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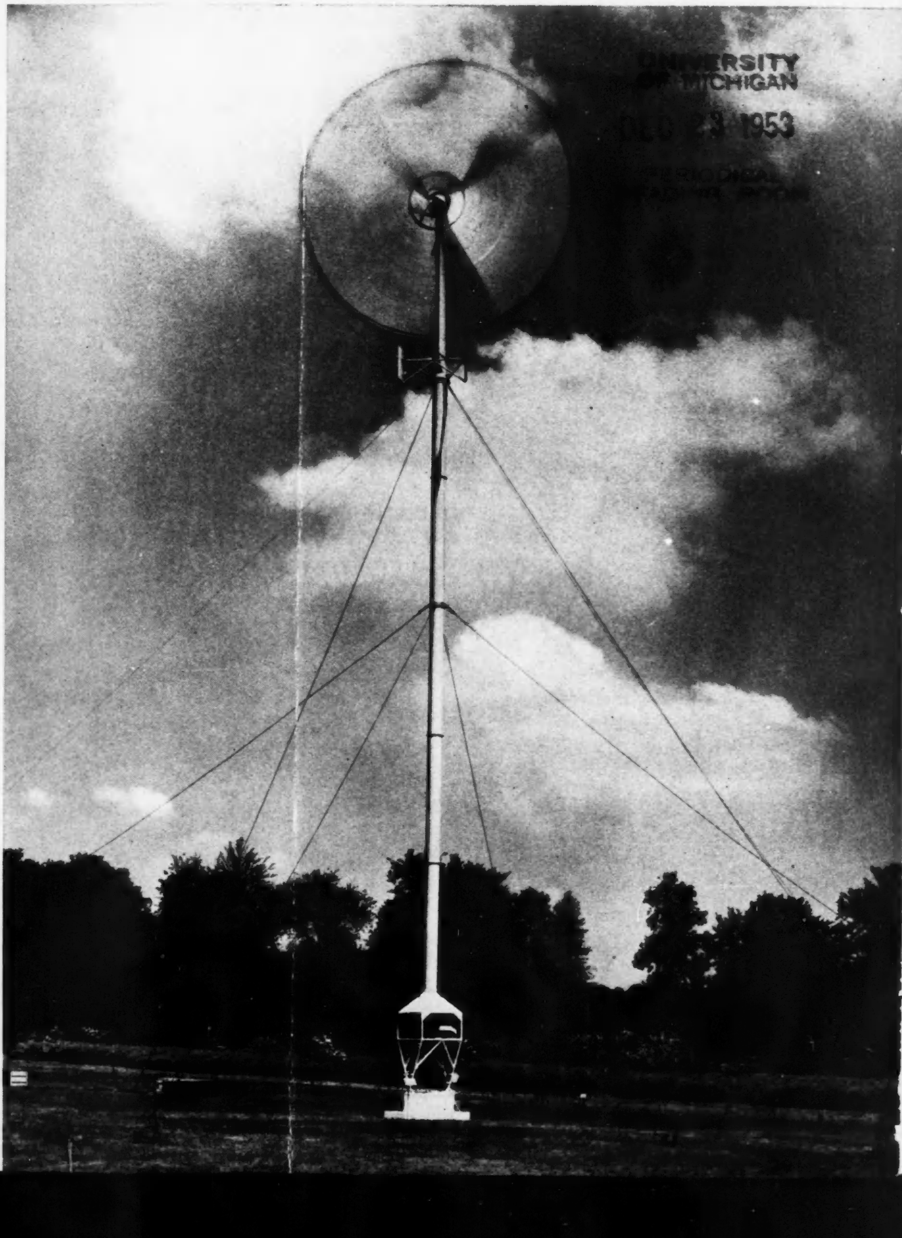

8-Kilowatt Andreau-type aero-electric generator. (*Enfield Cables photograph*)

Discovery

THE MAGAZINE OF SCIENTIFIC PROGRESS

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THE PROGRESS OF SCIENCE

THE DISPOSAL OF ATOMIC WASTE

The report of a comparative study into a number of different methods for disposing of unwanted Atomic waste, undertaken by three scientists of the Massachusetts Institute of Technology has appeared in *Nucleonics*.

The scientists (Drs. A. C. Herrington, R. E. Slaver and C. W. Sorenson) point out that the present method of storing these waste liquids in use at the American atomic centre at Oak Ridge, is dangerous. The waste products from the plant are first evaporated to reduce the liquid content and then stored in metal barrels. The danger of the barrels corroding and then leaking is considerable, and this method of disposal can therefore only be regarded as temporary.

The amount of waste liquid produced at Oak Ridge each day is considerable; its bulk is about 2000 gallons per day and its radioactivity amounts to about 20 curies per litre. This high figure is due to the fact that all effluent which shows any marked radioactivity must be stored. The only effluent which can be discharged is that having such a low degree of radioactivity that it would be impossible for harmful concentrations to be built up in the air, water, or vegetation with which it comes into contact following discharge. All storage tanks must not only be shielded in order to protect personnel, but they must also be leak-proof, otherwise radioactivity may be built up in the soil surrounding the tanks and may become concentrated in the plant life near them.

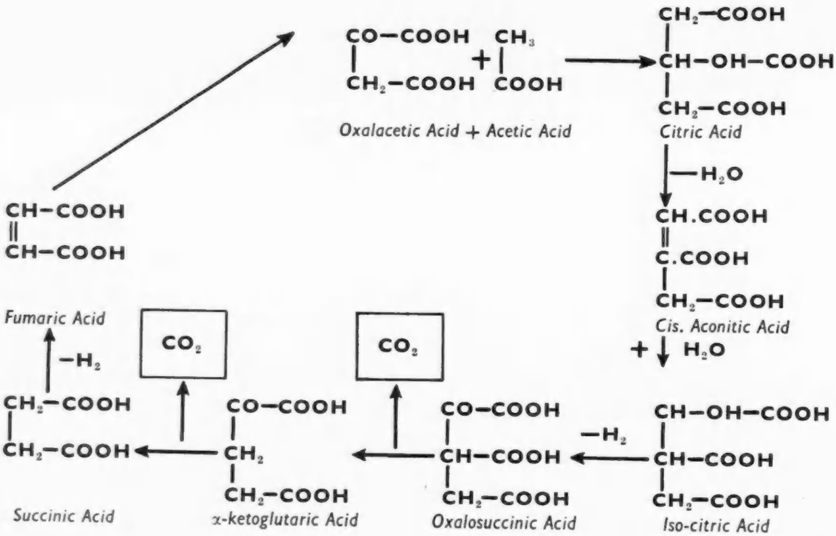
The radioactivity of the material falls away during storage through decay, but the reduction over a period of five years is only around 2%. While this reduction is considered sufficiently large to make the temporary storage of the materials with a view to their future use uneconomic for periods longer than 5 years, it does not significantly reduce the danger of the products.

Four of the five methods of disposal which were investigated involved a preliminary evaporation process in order to reduce the quantity of material which must be stored. The waste liquids could, however, be pumped into dry cells without any preliminary treatment at an estimated cost of 0·586 dollars per gallon of fluid. The cost of the present 'temporary' barrelling is 0·44 dollars per gallon of crude unevaporated waste.

The most expensive process proved to be that of fusing the evaporated waste products in glass prior to burying them in the land. The cost of this was estimated at 1·267 dollars per gallon of crude waste.

More promising were the three methods involving the incorporation of the evaporated liquid wastes into concrete mixes. Here the waste liquids would take the place of the water in the concrete mix and the resulting monoliths of concrete would be buried either in the ground or in the sea. A spot 500 miles off the coast of Georgia where the ocean has a depth of 15,000 feet, and the water at bottom 100–200 feet is stagnant, was suggested for sea burial.

The costs for these three processes were estimated to be between 0·581 and 0·653 dollars per gallon of waste. The authors rejected the possibility of embedding the waste materials in ceramics and the use of sulphur infusion, as impractical, though L. P. Hatch of Brookhaven, writing in the same issue of *Nucleonics*, has contested their dismissal of the former idea. He believes that ceramics are of considerable interest as possible containing materials in the case of highly radioactive waste. The investigators considered that the use of co-precipitation and electrolytic deposition techniques in place of evaporation as a method for concentrating the fluids, gave no advantages.



THE KREBS (CITRIC ACID) CYCLE

THE 1953 NOBEL PRIZES

This year's Nobel Prize for Physiology and Medicine (worth approximately £12,000) is shared by two German refugees. One of them, Prof. Hans Adolf Krebs, has worked in England since 1933; his explanation of his departure from Germany is both brief and comprehensive—"I am a Jew. The Nazis didn't like Jews." His co-prizewinner is Fritz Albert Lipmann, and before the Nazis came to power they both worked at the Kaiser Wilhelm Institute for Biology in Berlin. Lipmann, too, decided that Nazi Germany was an unhealthy place and went to Copenhagen, where he stayed for seven years before pulling up his roots once more and seeking safer asylum in the U.S.A. He is now Harvard's Professor of Biological Chemistry and director of a research team at the Massachusetts General Hospital.

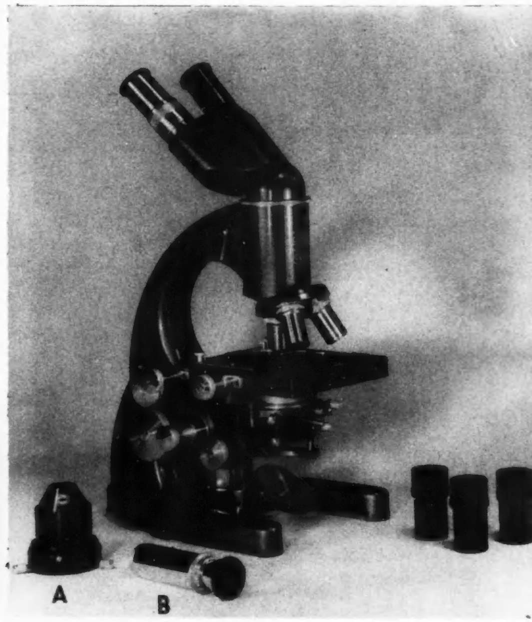
Krebs and Lipmann have worked in very much the same field, and it is quite appropriate that they should divide the prize between them, in the same way as Eijkmann and Gowland Hopkins shared the Physiology and Medicine Prize in 1929, and as happened in 1922 when this award was shared by A. V. Hill and Otto Meyerhof. Both men have worked out many details of the related and fundamental biochemical processes involved in the metabolism of carbohydrates, proteins, fatty acids and steroids.

Krebs has concentrated in particular upon the sequence of chemical reactions involved in the release of energy from food. This line of physiological chemistry has attracted many notable research men ever since the beginning of the 19th century when Gay-Lussac suggested that the key energy-releasing process was the conversion of glucose sugar into alcohol and carbon dioxide. That hypothesis may look rather primitive in the light of modern knowledge, but it certainly served the very fruitful purpose of opening up some very profitable lines of investigation. Today glucose still occupies the centre of the metabolic picture, for it is into glucose (or rather glucose *phosphate*) that both starch (the plant's reserve carbohydrate) and glycogen (the animal equivalent of starch) are converted. This sugar plays a vital role in anabolic processes as well as in catabolic processes. When either starch or glycogen is being mobilised by the plant or animal body the glucose appears in the form of *glucose 1-phosphate*. This compound is the starting point of one very important chain of reactions which ends with the production of the compound called *acetyl phosphate*. (Note that the phosphate radical is involved throughout this chain of reactions; this participation of phosphoric acid in carbohydrate metabolism is all-important, and probably it has been involved in energy-producing reactions ever since life first appeared on the earth's surface.)

Acetyl phosphate, to quote the late Sir Jack Drummond, is a key substance, not only in the chain of carbohydrate breakdown by living cells, but in both anabolism and catabolism of the other major food components: "it is

PROF. H. A. KREBS

PROF. F. A. LIPMANN



(Left) Prof. Frits Zernike. *(Right)* A modern research microscope equipped for phase-contrast microscopy invented by Prof. Zernike. In the foreground: *(A) the condenser* with the additional centring screws to align the special diaphragm incorporated in this unit: *(B) the telescope* used to align the diaphragm in the condenser to the phase-changing pattern on the plates in the rear focal plane of the objective lenses. Shown on the right-hand side are the boxes for the special objective lenses. *(Courtesy, C. Baker, London.)*

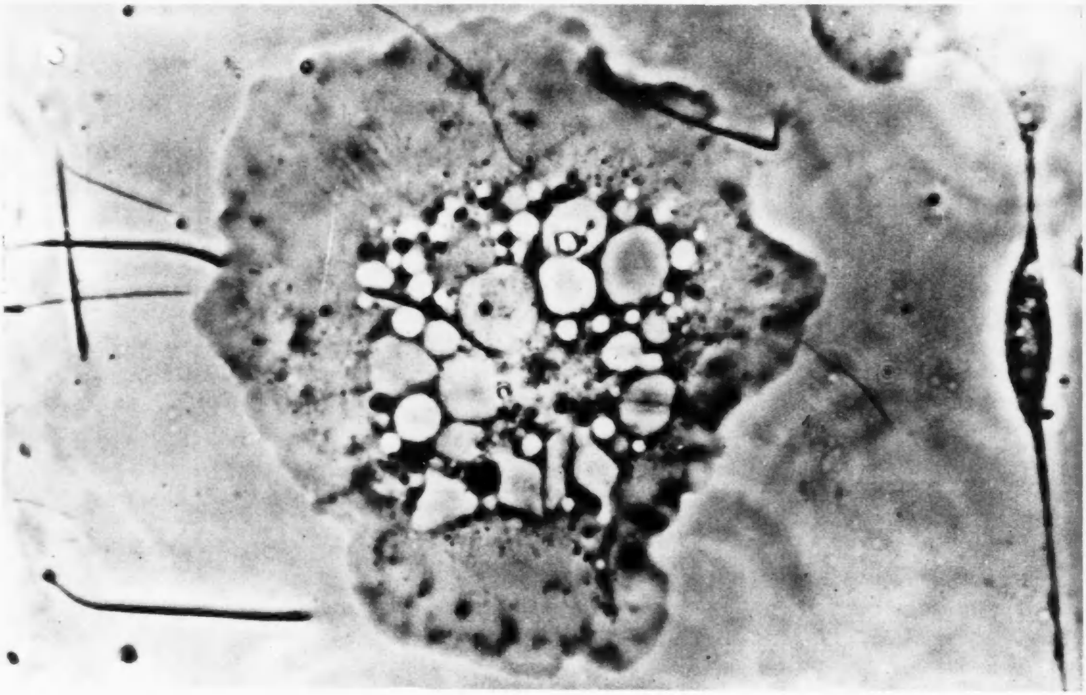
certainly related to the synthesis of fat, whilst there is a deepening impression that it is no less important in protein formation and breakdown". The cycle of biochemical changes which is known as "the citric acid cycle", or more shortly as the Krebs cycle, starts with acetyl phosphate. The details of this cycle, shown in the accompanying diagram, were worked out mainly by Krebs. Each step in the cycle is controlled by a highly specific enzyme.

The story of Krebs's main researches can be traced in a long series of papers beginning in the *Zeitschrift für Physiologische Chemie* and continued from 1935 in the *Biochemical Journal*. In the latter he has already published some fifty papers, sometimes alone and sometimes with collaborators, notably L. V. Eggleston. (These references cover other researches besides those concerned with the Krebs cycle; there is, for instance, his work on the formation of glutamic acid in brain tissue and on urea synthesis in the liver.)

Some of his papers are devoted to matters of biochemical method, such as the delicate experimental technique using an optically active molybdenum compound to estimate micro quantities of *iso*citric acid, and the use of the enzyme, carbonic anhydrase, as a tool in studying the mechanism of enzymic reactions involving carbonic acid, carbonate or bicarbonate.

To Krebs and his fellow workers in the difficult field of cellular metabolism we are indebted for the general recognition of the fact that most vital reactions, as for example those that make up the Krebs cycle, proceed not directly but in successive steps, the interruption of any one of which completely stops the process as a whole unless the organism can improvise an alternative route. Such improvisation is of medical significance, for it is one means by which pathogenic organisms become insensitive to chemotherapeutic agents designed to destroy them.

Krebs's work is essentially fundamental research, which has relevance however to certain basic medical problems, as was indicated in the last paragraph. This is doubtless a satisfying thought to Krebs who originally qualified in medicine, gaining his M.D. at Hamburg in 1925; his father was a physician by profession so that medicine is in the family tradition. Born in 1900, he had the benefit of studying at a number of important research centres including Göttingen, Freiburg, Munich and Berlin. He also had the advantage of working under inspiring teachers, who included two Nobel Prizemen—Otto Warburg and Sir Frederick Gowland Hopkins. He worked in Warburg's laboratory from 1926 to 1930. It was in 1933 that he arrived in Cambridge to work, first as a Rockefeller research student, and as a demonstrator in biochemistry. He was associated with Gowland Hopkins's team until 1935, when he went to Sheffield as lecturer in pharmacology. He has remained in that university ever since, transferring to the biochemistry department in 1938 and becoming professor of biochemistry in 1945.



Phase-contrast photomicrograph of a living wandering cell (amoebocyte) from the body-cavity fluid of the earthworm (*Lumbricus*). Here we see a broad expanse of almost structureless cytoplasm surrounding a small nucleus around which are arrayed a number of different kinds of granules and vacuoles. The long dark rods are spermatozoa. (*Courtesy, Dr. G. N. C. Crawford, Dept. of Human Anatomy, Oxford University.*)

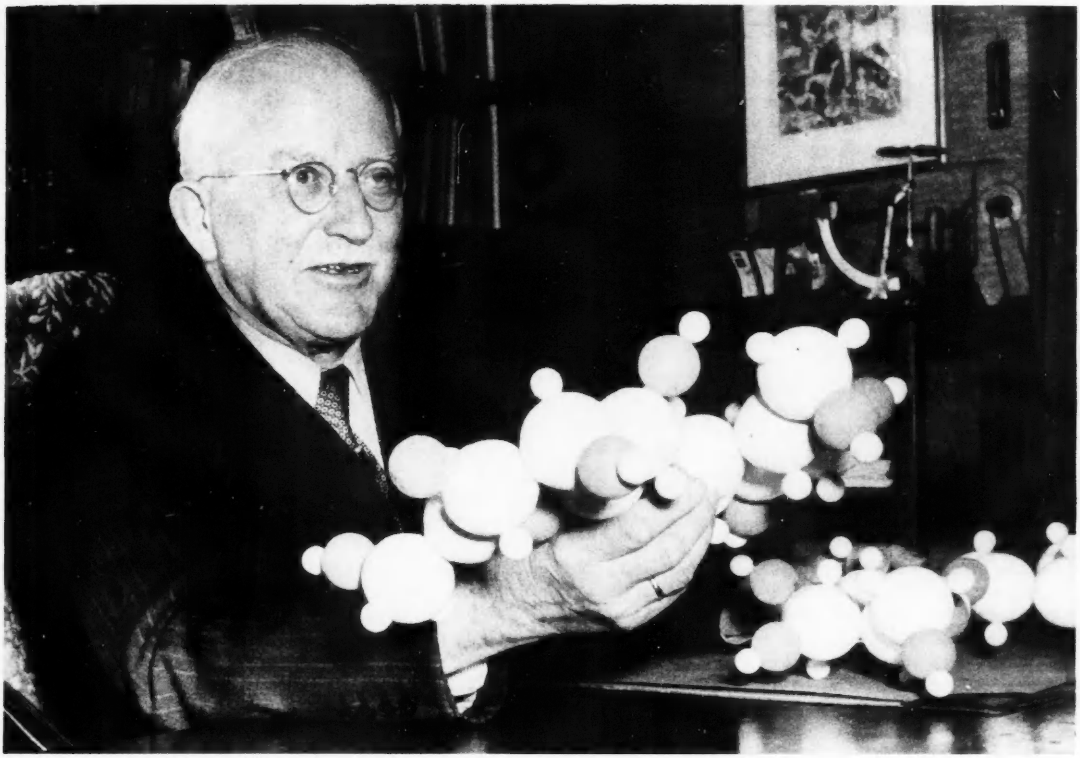
Lipmann's work links up with Krebs's. One of his notable discoveries was the isolation in 1945 of coenzyme A, which has a triggering action on a reaction connected with the body's synthesis of certain vital substances such as fatty acids and steroid hormones.

The Physics Prize has gone to a Dutchman, Frits Zernike who is Professor of Theoretical and Technical Physics at Groningen University, Holland. Last year DISCOVERY published a Progress of Science note about his work under the heading "Revolution in Optics", in which we referred to his investigations leading to the development of phase-contrast microscopy. Readers will recall how in that note we justified the description of Prof. Zernike as the greatest modern worker in the field of optics.

Born in Amsterdam in 1888, Zernike's early researches were concerned with the opalescence of liquids near the critical point, with solid state physics and with spectroscopy. He made important contributions to the theory of probability, and wrote a standard article on this subject in the German *Handbuch der Physik*. His great versatility was further demonstrated by the improvements he made to the construction of electromagnets, and by the designing of a type of a sensitive galvanometer which is generally known by his name.

Since 1933 Prof. Zernike has concentrated on optics. His outstanding contribution here was the invention of the phase-contrast technique, which was first used for testing mirrors used in reflecting telescopes. Later it was adapted to microscopy, and the importance of the phase-contrast microscope is difficult to overestimate, particularly in the biological field. It has enabled transparent objects such as living cells to be studied under excellent optical conditions such as were previously unattainable. Today the phase-contrast microscope is being used to an increasing extent all over the world and is now regarded as an indispensable piece of equipment in many biological laboratories. This in itself has been a major contribution to science, but in addition Zernike's work on phase contrast has enormously extended our knowledge of the mechanism of optical image formation, and this has greatly stimulated the development of optics in general and of microscopy in particular. People in all parts of the world have been searching for new methods of examining transparent objects, particularly by interference methods, but it is doubtful whether this work would have started if it had not been for the stimulus provided by Zernike's ideas on phase contrast. He and his pupils have added considerably to the knowledge of the part played by the diffraction of light in image formation, and a summary of developments in this direction was given a few years ago when Zernike gave his Thomas Young lecture to the Physical Society. The importance of his contributions to science was recognised by the Royal Society in 1952 by the award of the Rumford Medal.

The chemist honoured in the 1953 Nobel Prize list is Hermann Staudinger, Emeritus Professor of Chemistry



Professor Hermann Staudinger, winner of the 1953 Nobel Prize for Chemistry for his work on macromolecules.

and director of the Institute for Macromolecular Chemistry in Freiburg University in West Germany. He is renowned for his work on macromolecular structure, which originated from his interest in the constitution of albumen, cellulose and rubber. The official announcement of his award stated that his important work was certainly done many years ago, but that it had become fully recognised in the past few years, not least because of the part that plastics (which are high polymers) now play in industry. One cannot help wondering whether the Nobel award committee can justify its delay in recognising the importance of Staudinger's researches so until late in his career. Staudinger is well over 70, and it is now about 45 years since the key ideas of Baekeland were published, ideas that opened up the way for the modern plastics industry that owes so much to the fundamental studies of Prof. Staudinger. Nobel conceived his scheme for annual prizes in science and literature with the intention that they should be an encouragement to active research workers and writers who were still writing at the time they received their awards. The Nobel Foundation is evidently concerned about the fact that the awards do not always fulfil their founders' original intentions: for instance in the book which was published to mark the 50th anniversary of the first awards* one finds this remark: "The average age of the [literary] prizewinners can be figured at 62, which is, of course, rather high. It now remains to be seen whether in the future it can be brought down." The implication is even more vital to the healthy functioning of the Nobel Prize system as it affects science. One can congratulate the award committee on its choice of a man of 53, Prof. Krebs, in the Physiology category, but surely it should have been possible to recognise the talents of a man like Staudinger long before he reached the age of 72. Even the fact that Germans were not allowed to receive Nobel Prizes in the days of the Nazi régime is insufficient explanation of the delay in giving Prof. Staudinger a prize.

Professor Staudinger was born at Worms on March 23, 1881. In a long academic career, he became successively the head of the organic chemistry department of the Karlsruhe Chemical Institute (1907) and professor of inorganic chemistry at the Eidgenossische Technische Hochschule, Zurich (1912). In 1926 he left Zurich to take up the appointment of professor of organic chemistry at Freiburg University. As head of the university's chemical laboratory, he maintained his interest in the study of molecular structure, and in 1938 he added a research laboratory for macromolecular work. Prof. Staudinger is a member of numerous German and foreign scientific societies, and holds the Emil Fischer memorial plaque of the Association of German Chemists. When, in 1947, the journal *Makromolekulare Chemie* was founded, Staudinger was one of the principal promoters and he is now its editor.

**Nobel: The Man and his Prizes*, edited by the Nobel Foundation, Stockholm, 1950.

OPERATION TOTEM

Operation Totem, the first test of a British atomic weapon on the Australian mainland, was successfully completed at 7 a.m. on the morning of Thursday, October 15.

As a member of a small party of press observers, I was able to witness the explosion from a ridge between thirteen and fourteen miles from the steel tower on which the weapon was placed.

Unfavourable weather in the form of freak upper winds had held up the test which was scheduled to take place on October 8. But when we arrived at the test site just after dawn on the morning of the explosion, the weather was fine with both upper and ground winds blowing, in the required north-easterly direction which would take the radioactive cloud away from the pastoral areas.

The testing ground had been prepared in great secrecy in a dry, uninhabited area of scrubland about 350 miles north-west of Woomera, the base of the Long Range Weapons Establishment. The desert there is made up mainly of red clay, part of which had been bulldozed to form an airfield called Emu Claypan, after which the whole site has now been named.

Some thirteen miles from the airfield a steel test tower had been set up with several roads radiating out from it. Along these roads a target array of one tank, six obsolete fighter planes, lorries and various kinds of ammunition and equipment had been laid out. Dummies dressed in Service uniforms were also exposed to the weapon. In addition there was, of course, a large array of instruments to record the flash, heat effects, blast and gamma radiation. The Supply Ministry's remarkable camera, which is capable of taking pictures at a rate of 100,000 a second, had been set up to photograph the explosion during the first few millionths of a second of its development.

When we arrived at our observation post, we were told over loudspeakers that the test had already entered its seventh phase, code-named Platypus, which involved the final priming of the weapon on the tower and the evacuation of all people from the danger zone.

About forty minutes before zero hour the ground had been cleared except for one unnamed scientist whose duty was to press the switches controlling the firing mechanism and plug in a firing key, turning it from SAFE to FIRE. There was no danger that the weapon would explode prematurely as this man drove back to the firing point in a Land Rover, which sent up a cloud of dry dust, for in his pocket he carried the safety link, a device without which the master switch would not work.

As the scientist handed over the safety link to the test controller, the operation shifted into its final pre-explosion phase—called Wombat—in which all personnel were accounted for. The Australian troops, numbering 180 in all, who had worked for months to build the site under harrassing conditions, formed up on a hill nearby. Then over a loudspeaker the voice of Captain Pat Cooper, Sir William Penney's technical assistant, warned us that the last four minutes before the explosion would be counted aloud.

We were given the choice of facing away from the first flash of the explosion or of watching it through welders' goggles. I put on the goggles and precisely at 7 a.m. at the end of a staccato count of five, four, three, two, one, ZERO . . . a brilliant pin-point flare appeared on top of the tower, expanding rapidly into an immense fireball.

A shock-wave moving upwards and outwards was visible through the goggles. Then with the naked eye I watched the fireball change from orange and red to dark brown. I was so fascinated with the development of the fireball, and the subsequent cloud which slowly took on the typical mushroom shape, that I was not prepared for the arrival of the noise of the detonation. It reached us 57 seconds after the flash as a sharp double crack which rumbled through the desert for half a minute.

Sir William Penney, who had planned and supervised the test but was never visible to us, had predicted a double bang under the prevailing atmospheric conditions. The pressure wave thrown out by the explosion had two sharp peaks which were sufficiently separated in time to be heard in succession.

Sir William had also rightly predicted that the cloud would not be particularly spectacular. The visible cloud of an atomic explosion goes much higher if a substantial amount of water vapour is taken up with it. In this case, the desert air was so dry that the cloud did not rise much above three miles. It was mainly brown in colour because of large quantities of nitrogen peroxide formed from the air.

The cloud was also comparatively small because the yield of the weapon was considerably less than 'nominal', i.e. its power was less than that of the Hiroshima bomb. Unofficial estimates put it as equivalent to between 10,000 and 15,000 tons of T.N.T. compared with the 'nominal' bomb's 20,000 tons. This reduction—which is understood to be due to a reduction in the fissile content of the bomb made possible by a more efficient detonating mechanism—puts the weapon in the 'tactical' class, meaning that it could be used against specified objectives.

There is no official confirmation that the weapon tested was in fact a bomb, but it is a reasonable assumption that the R.A.F. must have first call on Britain's limited stocks of atomic explosive.

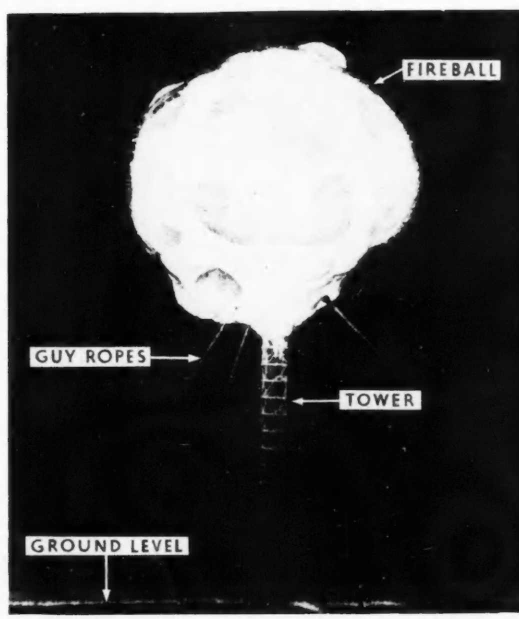
About fifteen minutes after the blast, by which time the mushroom cloud had been blown off its stalk by the wind, a Canberra bomber flew over the devastated area to collect air samples. When the pilot radioed 'All safe', teams of scientists in protective clothing began to edge their way with Geiger counters towards ground zero so that instruments could be recovered.

Half an hour later we were flown over the target area at a height of little more than a thousand feet. The steel tower on which the weapon was detonated had entirely disappeared. In its place there was a shallow crater burnt to a metallic grey by the intense heat of the fireball, which for a moment had sat on the desert. Farther out from the crater bushes were smouldering and tough mulga trees had been snapped off by the blast.

The planes and vehicles in the target array seemed unharmed but no doubt were dangerously radioactive. Concrete experimental air-raid shelters set up near ground zero seemed to have withstood the blast.

CHAPMAN PINCHER

The atomic weapon tests held near Woomera in October were directed by Sir William Penney (*right*) and Mr. C. A. Adams, scientific superintendent for the tests.



(*Left*). Two atomic weapons were exploded in the Woomera tests. This is a picture of the first explosion, the one described by Chapman Pincher. (*Right*) An American atom bomb picture just released by the U.S. Atomic Energy Commission. This remarkable photograph shows the fireball beginning to vaporise the tower on which the atomic bomb stood. According to a report in *Time*, it was taken with a special camera made by Edgerton, Germeshausen & Grier. Inc. of Boston. Its shutter has no moving parts, only two sheets of polarising material something like the stuff in the glasses that are used to view 3-D movies. When light passes through the first of them, it is polarised so that its waves vibrate in a single direction. Then it cannot pass through the second sheet, whose plane of polarisation is set at right angles to that of the first sheet. In this condition the shutter is closed.

Between the two sheets is special glass surrounded by a coil of insulated wire. When a powerful current from a condenser is shot through the coil, it creates a magnetic field in the glass which rotates the light waves so that they pass through both of the polarising sheets and reach the film of the camera. The light can pass only while the current is flowing, so a very short pulse opens the shutter for as little as one-millionth of a second. Some such speed was necessary to picture the doomed tower when it was only half-vaporised by the hungry fireball.

JOHN DEE (1527-1608)

G. VAN PRAAGH, B.Sc., Ph.D.

The scientific renaissance, usually attributed to the seventeenth century, can be traced back farther and in the previous century one finds that John Dee, now generally known only as an alchemist and sorcerer, was in fact a pioneer in several of the main branches of science in Elizabethan days. In his breadth of interests, intellectual power and vision, he is an outstanding representative of the rebirth of science in the sixteenth century.

Born in 1527, Dee went from Chelmsford Grammar School (where he was "metely well furnished with the Latin tongue") to St. John's College, Cambridge. Here he was "so vehemently bent to studie" that for those years he slept only four hours every night, allowed two hours to meat and drink and "of the other eighteen hours, all (except the time of going to Divine Service) was spent in my studies". On leaving Cambridge, Dee visited the Low Countries, where he became friendly with mathematicians and other scholars, including Mercator, who gave him some mathematical instruments.

When only 23, Dee lectured at the University of Paris on the Elements of Euclid to crowded audiences. This he did "freely and publicly, for the honour of my country, a thing never done in any University of Christendom". These lectures aroused great wonder and gained him fame as an original mathematical thinker. He was later to write a long preface to the first English edition of Euclid. This preface has been described as "one of the peaks of sixteenth-century scholarship" and is probably Dee's most notable achievement. Despite its importance and originality, it was not primarily addressed to scholars, but was a short, popular account of Dee's scientific ideas. In it he describes more than thirty special sciences growing from "this mighty, most pleasant and fruitful mathematical tree". For example, Arithmetic is described as "next to Theology, most divine, most pure, most ample and most general, most profound, and most subtle, most commodious and most necessary". Under Optics, in speaking of perspective glasses, he foreshadows the telescope, and describes convex mirrors, then a novelty. Under Statics, he follows the argument of an Italian, Bennedetti, and states that, contrary to the accepted Aristotelian view, all bodies fall at the same rate, no matter what their weights. Galileo, to whom this discovery is usually attributed, was then but six years old. This preface concludes with an eloquent plea for the publication of scientific works in English.

His studies both at home and abroad led Dee to draw up, in 1556, a "Supplication to Queen Mary for the Recovery and preservation of Ancient Writers". Dee had seen the treasures of the monasteries dispersed and appealed for a search for precious manuscripts before they were irretrievably lost. He proposed that both British and foreign manuscripts should be copied and kept in a national collection, and that printed books should be "gotten in wonderful abundance". However, nothing came of this proposal, which Dee made fifty years before Thomas Bodley opened his collection at Oxford and two hundred years before the British Museum Library was founded.

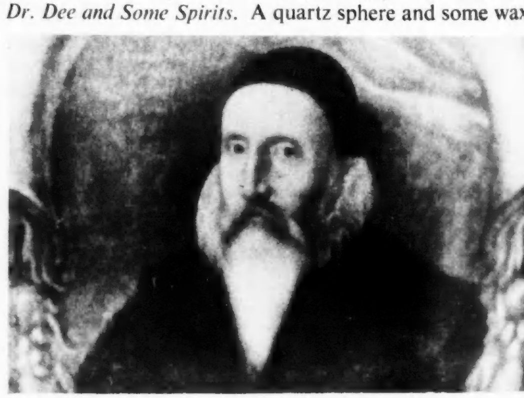
Dee built up a private collection of over 4000 books and manuscripts, which he kept at his riverside house at Mortlake. Historians, physicians, geographers and members of Queen Elizabeth's court came frequently to his house to consult him and to use this library. Dee copied many books himself, and Norton's *Ordinall of Alchemy*, beautifully transcribed by Dee in 1577, may be mentioned as an example of his industry. Queen Elizabeth called more than once to see Dee at Mortlake. When a wax image of the Queen was found with a great pin through its breast, a supposedly dreadful omen, Dee was hastily summoned to the court (then at Richmond) to allay their superstitious fright.

Our knowledge of Dee comes from a number of his manuscripts and printed books which are preserved in the Bodleian and British Museum Libraries and which include his Private Diary, a series of notes written in the margins of printed almanacs.

Dee had a lifelong interest in navigation and exploration and his diary records his friendships with Raleigh, Frobisher, Gilbert, Hawkins, Hakluyt and others. In his *General and Rare Memorials Pertaining to the Perfect Art of Navigation*, Dee urges, among other things, the formation of a "Petty Navy Royall of three score tall ships or more. . . . What a comfort and safeguard to the Realme to have so many war-like ships, well manned and appointed, ready to affront, set on and overthrow any sudden foreign treachery by sea attempted against this Empire."

Dee was later commissioned to reform the calendar, and his work and suggestions are described in a manuscript entitled *Humble Advice for Our Gracious Queen Elizabeth Concerning the Reformation of the Calendar, 1583.* His recommendations were not adopted until 170 years later.

England's foremost mathematician, eminent astronomer and alchemist, Dee was also an astrologer, though within the context of his times there was nothing surprising in this. In spite of his extensive reading and wide travels, he desired further knowledge and, at the age of 54 he took up crystal-gazing. He employed a medium, Edward Kelly, and the accounts of his séances, conscientiously recorded in detail by Dee, fill many manuscript volumes. Some were printed in 1659 under the title, *A True and Faithful Relation of What Passed for Many Years between Dr. Dee and Some Spirits.* A quartz sphere and some wax



tablets which he used in his crystal-gazing are preserved in the British Museum. Unfortunately these activities of Dee, which only dominated six or seven years out of his life, have coloured the popular impression of him.

In 1583 Dee was introduced by Leicester to a Polish nobleman, Count Laski. Soon afterwards, Dee and his family left secretly for Poland, and went on to Bohemia, where Dee lived for nearly six years, practising alchemy and crystal-gazing. He communicated occasionally with Queen Elizabeth and some think he was sent to Europe as her spy. Robert Hooke suggested this theory, but there seems little evidence for it. While in Bohemia, Dee was in contact with the Alchemist-King, Rudolph II, and read him some of his works. In his alchemical notes, Dee emphasised the importance of the balance and the quantitative recording of results. His mathematical thought led him to speculate on how the properties of a substance might result from the geometrical arrangement of its particles.

While Dee was living in Bohemia, the mob broke into his house and destroyed a large part of his possessions. The damage to his library was estimated at £3000. In listing "the contents of my late, spoyled Mortlake Library", he includes "one excellent and fair quadrant (made by the famous Richard Chancellor) of five foote diameter, cost 20 pounds; but now I find it most barbarously spoyled and with hammers smitt in pieces. There was an excellent radius astronomicus of 10 foote long, two globes of Gerardus Mercator's best making; and there was a magnesstone, commonly called a loadstone, of great vertue, which was sold out of my library for 5 shillings, and for it afterward, yea piece-meal divided, was more than £20 given."

Dee's old age was marked by disappointment and disillusion. He was several times promised financial help by the Queen, but when he was eventually given the wardenship of Manchester College, it proved an inadequate source of income. He died in poverty and was buried in the church at Mortlake.

WILLIAM GILBERT'S CENTENARY

It is 350 years ago this month since the death of William Gilbert, a man who, even in his lifetime, was recognised as outstanding and that in an age which was itself exceptional for its men of talent in every sphere of learning.

He came from an old and respected Suffolk family, and was born in Colchester in 1544, one year after Copernicus published his revolutionary theory that the sun was the centre of the planetary system.

Gilbert entered St. John's College, Cambridge. He took a degree in medicine and eventually became a senior fellow of the college. After leaving Cambridge, he practised in London. He gained the appointment of Physician to Queen Elizabeth I, and his medical contemporaries honoured him by electing him President of the College of Physicians.

"A fool is a man who never tried an experiment in his life," said Erasmus Darwin over two centuries after Gilbert's death, yet this might have been the slogan of the man who wrote the first great British work on physics and who led the field in the adoption of the experimental approach to science.

Gilbert discovered the simple laws of attraction and repulsion between the poles of a magnet and investigated the phenomenon of the angle of dip, constructing the first dip circle. He also carried out some work in electrostatics and gave the words 'electricity', 'electrical force', 'electrical attraction' and 'magnetic pole' to the world of science.

After years of investigational work Gilbert, in 1600, published *De Magnete*, a book "On the magnet and magnetic bodies and on the great magnet the earth", which in presentational method might have been written within the last century. It contained a survey of the then existing knowledge of the subject of magnetism followed by a detailed survey of the experiments he had performed and a discussion on the results obtained.

He hit upon the then novel idea of using a small scale model for his experiments—a large sphere of magnetised iron representing the earth—and from this concluded that the earth was one vast magnet. His hypotheses though untenable today still provide a useful picture where no complete theory prevails.

It is interesting to note that in October 1945 Professor S. Chapman wrote, in a DISCOVERY article entitled "The Earth's Magnetism", "The main fact that the earth is a great magnet remains an unsolved problem, a standing challenge to theoretical physics." Later still, in 1947 to be exact, Professor P. M. S. Blackett, writing in *Nature* (Vol. 159, p. 658), was occupied with the query of Schuster, which had been laid aside since 1891, namely, "Is every large rotating mass a magnet?"

Dr. Gilbert's work commanded the respect not only of Queen Elizabeth but also to such mighty contemporaries as Galileo and Bacon, two great champions of the new experimental approach to science. Certain it is that his experiments delighted his illustrious monarch and her naval chiefs who gathered to see the attraction of small non-metallic objects to amber—the amber from whose Greek name Gilbert coined the term 'electricity', a word which we now hear so often in our everyday lives. One may well ponder whether Shakespeare's words in *A Midsummer Night's Dream*:

> "You draw me you hard-hearted adamant
> And yet you draw not iron,"

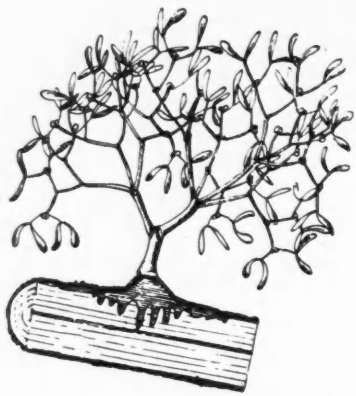
and again

> "Your eyes are lodestars."

were an indirect result of the interest aroused in matters of magnetism at the court where both author and scientist were so highly respected.

With the passing of the Tudors came the death of Gilbert on December 10, 1603, and as if fate decreed to leave no trace of this eminent son of East Anglia, his books perished in the Great Fire of London. But today Gilbert is hailed as the "Father of Magnetism", and as Dryden prophesied, "Gilbert shall live till Lodestones cease to draw".

E. V. SMITH



A mistletoe bough taps the sap of its host plant by means of 'suckers' (often called haustoria). *After Bjorn Ursing's "Svenska Vaxter," Nordisk Rotogravyr*, 1945.

MISTLETOE: ITS LIFE AND LEGENDS

B. BARNES *D.Sc., Ph.D., F.L.S.*

Among the many mistletoe legends is the famous one about Balder who was struck down by a spear made out of mistletoe, the only thing on this earth to which he was vulnerable. Afterwards the Gods decreed that mistletoe should never touch the earth again, which is the reason that it is hung high at Xmas. Mistletoe's name derives from *mistel-ta*, which perpetuates the erroneous idea that this plant is propagated by bird droppings. Dr. Barnes's article deals with the familiar mistletoe of Europe, *Viscum album*. American Mistletoe is a different but related plant, *Phoradendron flavescens*; this is the State flower of Oklahoma. In Australia the name is applied to any plant of the Mistletoe family (Loranthaceae); one Australian genus, *Notothixos*, parasitises other mistletoes.

Mistletoe is rather like Wayland Smith in *Puck of Pook's Hill*: it has come down in the world. In former times the plant was surrounded by an aura of superstition, though it was not always clearly distinguished from the witches' brooms which are caused by the attacks of fungi or of mites, and are common on many trees. The sight of one kind of plant sprouting from the branches of another kind impressed our ancestors, coupled with the special conspicuousness of mistletoe in winter, with its green leafy branches seated on the leafless branches of trees, suggested that the spirit of the 'dead' tree was showing itself in a distinctive form.

Many races of men worshipped the oak, and it is not surprising that when mistletoe was found growing on oak, a rare occurrence then as now, it was thought to be specially sacred. The Druids had a deep respect for mistletoe on oak. They accounted it a heal-all, with particular powers of mitigating the disabilities of old age, and of promoting fertility in man and beast, an idea which may illuminate its only current significance, a significance for which we can offer no entirely satisfactory explanation. The Druids sought for the plant at the winter festival, when the days were darkest and the young sun of spring was still far away. Then they went in solemn procession to the sacred oak, sacrificed white bulls under the tree, cut the mistletoe with a golden sickle, caught it in a white cloth so that it should not lose its virtue by touching the ground, and with chant and ceremony distributed pieces of the plant to the assembled worshippers. Although mistletoe has no part in their proceedings, it may well be that Christmas waits and youthful carol-singers are the modern equivalent of these ancient rites, and that Christmas boxes have replaced the sprig of mistletoe handed by the Druids to their followers.

The 'Golden Bough' of Virgil and other classical writers, a talisman to living men who, with its protection, entered Hades and returned safely to the light of the sun, seems to have been a kind of idealised mistletoe; there grows in southern Europe a kind of mistletoe which is yellower than our plant. The subject is obscure, as is the choice in the Norse legend of mistletoe as the source of the dart which killed Balder. Mistletoe is unknown in Iceland, where many of the Norse legends were first put into writing, and it is (and was) very rare in Scandinavia. The legend of Balder is probably a poetic version of some story brought by the Vikings from a southern country.

In places where it abounds, mistletoe, together with holly, ivy, bays and other evergreen plants, has long been used in the greenery that is hung up to celebrate the turn of the year. For church decoration, however, mistletoe seems to have been somewhat suspect, at any rate in Britain, doubtless because of its heathen associations, though there are records of a Yuletide ceremony in York Minster, where mistletoe was carried in state to the high altar, and a general pardon was proclaimed. But the plant has long been used in the decoration of houses. Young men were permitted to salute any woman they found under the mistletoe and to pluck a berry for each kiss. Now, the age limit has been extended, maybe young men no longer need special encouragement or protection! This short period of frivolous use is now almost all that remains of the long and complicated series of ritual ceremonies connected with the plant.

In Britain mistletoe has no economic significance apart from its brief appearance at Christmas time. In central and south-east Europe, where the plant is abundant, it is cut as winter-feed for cattle, and some use is made of the fruits in decorated confectionery. These uses dispose of a widely held view that the plant is poisonous, but the berries do not seem to be well-flavoured, so that sentiment probably explains their use. The stems of mistletoe are rich in starch, and they have been used in times of scarcity in central Europe, being dried and ground up with rye to make bread. The scraps of mistletoe which have been found on the sites of pile-dwellings in Switzerland may be the remains of cattle-feed, or perhaps they were just brought in on pine branches used to thatch the huts or as bedding. Bird-lime used to be made from mistletoe berries.

The common mistletoe (*Viscum album*) is a small evergreen plant which lives as a hemi-parasite attached to the branches of a variety of woody plants, and it has a wide area of distribution in the temperate parts of the Old

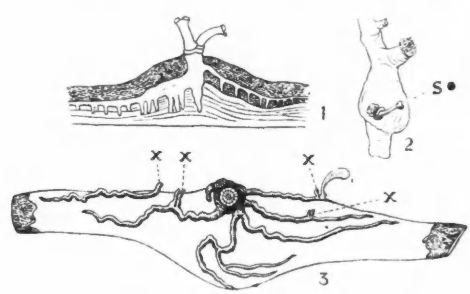
World. It ranges in Europe from the Mediterranean Sea to about 59° N. Lat., though it is rare in the northern part of its area, and spreads across Russia towards China and Japan; the Japanese plant may be a distinct species.

In the main area occupied by the common mistletoe, there are three distinct races, not very different in appearance, but very distinct in the host plants that they parasitise. Two races occur on coniferous trees, one on silver fir (*Abies pectinata*) and a few close relatives, the second on Scots pine (*Pinus sylvestris*), larch and a few related trees. Members of the first race do not grow on the host plants characteristic of the second race. The third race, the only race to be found in Britain, has as its hosts a variety of broad-leaved trees, and it does not inhabit coniferous trees. Mistletoe is not native to Scotland or Ireland, and in Britain it is to be found growing only about as far north as Yorkshire. In parts of southern England, as notably around Hampton Court Palace, it is common on lime trees, and it may be found also on willow, apple, poplar, maple, ash, hawthorn, sometimes on pear, and very rarely on oak. Much of the mistletoe sold at Christmas comes from apple. So rare is mistletoe on oak that its occurrence on that tree has often been denied, or explained by reference to a different species of mistletoe which grows freely on oak in southern Europe. There are, however, a number of reliable records from southern and western England, from France, and a few from Germany and Switzerland. The seedlings will start on beech, but they soon die on that tree, and mistletoe does not seem to grow on elms. Some hosts, such as the ash, are usually thinly colonised, but the plants they bear are often exceptionally strong. It is noteworthy that while mistletoe is frequently seen on black poplar, it does not seem to occur naturally on Lombardy poplar, which is a variety of the black poplar. This may be because the nearly erect branches of the Lombardy poplar are not convenient as perches for birds—birds distribute the seeds of mistletoe—but an additional explanation may be that the branches of the Lombardy poplar are often short-lived and fall in large numbers, and so may not be favourable to the establishment of the parasite. It is possible, too, that there is some physiological explanation, for the race of mistletoe which inhabits broad-leaved trees is certainly composite and needs extended experimental analysis.

Mistletoe always lives attached to some other plant—the host plant—and never sends roots into the ground. Indeed it has no true roots, for the parts of its body which attach it to its host are most probably highly specialised branches of the *shoot* of the mistletoe. It has green leaves, and therefore it can use carbon dioxide obtained from the air as a starting point for the making of food, and it probably takes little from the host except water and dissolved salts. The woody tissues of the mistletoe are intimately connected with those of the host, in which water and salts travel. In contrast, the basts (phloem) of the two plants, the tissues in which elaborated food travels, are not in close union. Food made by the mistletoe seems to be of no service to the host. If for instance the host is kept bare by the systematic removal of its leaves, while the mistletoe on it is allowed to retain its leaves, host and parasite die in about two seasons, suggesting that the mistletoe is contributing nothing to the economy of the combination. The relation between mistletoe and host is not the same as that when one apple shoot is grafted upon another; in such a graft, the leaves of the scion help to nourish the whole composite plant.

Much water vapour passes from the leaves of mistletoe into the surrounding air, and the parasite makes heavy demands on the water brought up by the host from the soil. When a plant of mistletoe has developed part-way along a leafy branch of a host, the outer part of that branch is sooner or later starved of water by the drain set up by the mistletoe. Then that outer part dies back to the place of attachment of the parasite. While this is going on, there is abnormal growth of the softer cells of the supporting branch below the place of attachment, causing swelling there. When the end of the host branch has died and fallen away, a club-shaped stump is left, with the mistletoe sprouting from the thick part of the club. On this the mistletoe may survive for some years, its leaves replacing those of the lost upper part of the host branch in promoting the upward flow of water, all now taken by the mistletoe. But, at last the support dies and breaks, either because the mistletoe cannot stimulate a sufficient flow of water, or because the weakened host-branch is killed by secondary parasites, or perhaps because there is a slow downward leakage of metabolic waste from the mistletoe which kills the support. Before the death of the support, it is easy to see that the mistletoe is weakening. An attentive examination of the old lime trees at Hampton Court will reveal all stages of these changes; fallen clubs are sometimes to be found under the trees; some of them are impressively large. We are not well-informed about the length of time required for the completion of these changes, for it is not easy to be sure of the age of a plant of mistletoe. The evidence to hand suggests that a plant thirty years old is a venerable ancient, and that the average duration of life is some twenty to twenty-five years. Yet it is not that the mistletoe dies of old age; it dies because it brings about the slow ruin of its support.

The forked branching of the mistletoe, with the groups of white berries between the paired short branches, is familiar enough from the plants put up for Christmas decorations. But these samples do not give the whole of the



Mistletoe: 1, longitudinal section showing attachment of parasite to its host. 2, seedling mistletoe at S. 3, branch of host plant with bark removed to show the absorptive system of the mistletoe; adventitious buds arise at X. (*After Unger and Macgregor Skene*).

story. Mistletoe is a dioecious plant; that is, male and female flowers form as distinct plants, and it is only the female plants that are gathered for sale. The twigs are covered by a dull green bark, and as they never form cork they remain green, though the older twigs are protected by the thickening of the walls of the cells on and just below the surface of the twig. The leaves are tough and yellow-green when young, becoming greener as they age, because with age they accumulate more chlorophyll. New leaves form in spring, as the plant is flowering; they remain in position throughout the next winter, and commonly fall during the ensuing summer, when the next crop of leaves is well advanced. Some leaves may last longer than this, especially on plants belonging to the races which inhabit conifers. When growth stops as summer goes by, each of the youngest branches ends in a large bud, flanked by a pair of leaves with a small bud between each leaf and the large bud. In young plants, the large bud perishes during the succeeding winter, but if the plant is mature—a condition reached some years after the germination of the seed—then in late March or early April, the large buds open and the flowers expand. Meanwhile each small bud produces new twig, and so, year by year, the plant increases in size. Towards the end of the year, male plants bear leafy shoots only, while female plants show pearly berries seated between the leafy twigs. In female plants especially, the regular forking may not be present, for additional leafy twigs sometimes arise around the group of berries.

The small yellowish flowers emit a rather weak odour which to some noses suggests oranges, but is better described merely as fruity. The male flowers open in clusters of four or five; the female flowers occur in twos or threes, and of these, all may not yield a berry. (These numbers are inconstant and not to be emphasised.) The flowers have no true petals; they each have four small, yellowish, floral leaves, conveniently named perianth segments. In the male flowers the pollen-sacs are united with the perianth segments, opening on the upper surfaces of these by pores, and producing a honeycomb-like appearance. The pollen is sticky and holds together in small clumps; it is carried by flies, and somewhat infrequently by bees, to the female flowers. The male flowers then shrivel and disappear. After pollination, the ovaries of the female flowers swell; their perianth segments, which are seated high up on the sides of the ovary, fall off to leave four scars, visible on the upper ends of the ripe berries in an attractive little pattern of four tiny dots. The berry is nearly ripe by Christmas, fully ripe in early February. It may be remarked in passing that this berry is not a true berry, and the seed presently to be mentioned is not a true seed.

There have been reports that plants of mistletoe can bear both male and female flowers at the same time, but they are unproved. Sometimes a plant of mistletoe will live parasitically on another mistletoe plant, and if one is male and the other female, there will be a deceptive appearance of a plant having both kinds of flowers. Often, seedlings establish themselves close together on the same host branch, and become intermingled as growth proceeds; this again might suggest a wrong conclusion.

In late winter, the berries of the mistletoe are eaten in large numbers by the missel-thrush, the only bird that seems to feed freely on them. The one or more seeds in each berry are surrounded by stiff, glutinous material produced by the breakdown of the fruit wall. This sticky mass incommodes the bird, which proceeds to clean its beak by rubbing it against a branch, and there leaves some seeds adhering to the bark by their slime. As the bird is most likely to perch on a horizontal or nearly horizontal branch, the seeds slide downwards and come to rest on the underside of the branch.

If, as usually occurs, the seed has stopped in a place where it receives light, then, as the weather warms up, it germinates. It contains an embryo, but unlike the embryos of most flowering plants, that of the mistletoe has no root rudiment. It has a thread-like structure, the hypocotyl—a hypocotyl is familiar in mustard and cress as the whitish thread between the young leaves and root—which emerges from the seed, eventually presses its end against the branch of the host plant, and there becomes flattened. From the middle of that flattening, a peg-like sinker grows out and forces its way through the bark of the host, going inwards until it reaches the xylem. Within the sinker a thread of woody tissue forms and links up with the xylem of the host. That is the beginning of the mistletoe's supply system. This is about as far as events go in the first season, and the seedling mistletoe has not yet produced a leafy shoot; but it is green, and so can assimilate carbon dioxide. During that first season, the host branch will increase in thickness by the usual growth processes and the sinker elongates accordingly and so is not buried by the enlarging branch. In the second season, a short leafy branch with a pair of leaves grows into the air from the summit of the sinker, and the sinker also produces, beneath the bark of the host, a thin cylindrical green runner which makes its way along the host branch, close to the surface of the wood, produces some secondary sinkers which behave like the first, and puts out into the air one or two separate leafy branches. In subsequent years, these events are repeated, the mistletoe spreading by runners beneath the bark of the host, putting down more sinkers, and forming more aerial branches. And, in step with this, the aerial branch systems fork and lengthen, until finally the flowering condition is attained. One seed may thus eventually produce several visible tufts of branches, and from this stage, growth goes on until the end comes in the manner already described.

This brief survey of a large subject can do no more than indicate some of the many points in the story of the mistletoe. A very detailed account of the plant, its history, biology and morphology, may be found in von Tubeuf's remarkable *Monographie der Mistel* (1923), though this is not available in an English translation. Sir James G. Frazer has dealt with the legends associated with the plant in his *Balder the Beautiful* (1913), and there are some curious details in Brand's *Observations on the Popular Antiquities of Great Britain* (vol. 1, 1849). Most botanical text-books give a general account of the plant, and there are many specialist papers in botanical periodicals. Yet, although the mistletoe has been closely studied by botanists, and has received much attention from anthropologists, there remains much to be cleared up—a remark that may equally well be made in reference to any of our commonest plants!

HARNESSING THE WIND

E. W. GOLDING
M.Sc.Tech., M.I.E.E.

In a "strong breeze" of 30 miles an hour a power of nearly 800 horse-power is passing through a vertical area one cricket pitch square. Such a wind speed, frequently occurring at many places in the world where electric power is wanted, and where there is no immediate prospect of its provision from supply networks, must be a strong incentive to the development of a practical means of extracting this power. It is perhaps pointless to attempt the calculation of the total amount of energy which is available annually in the winds over the earth's surface, but clearly it is enormous and, being inexhaustible, represents a source of annual 'energy income' which should be considered more seriously than it has been in the past by those who are searching for new methods of energy production.

There are, of course, valid objections to wind power when it is compared with power generation by coal or other fuels, or by water. The main one is its fickleness; even at the windiest sites which may be discovered, the wind speed is variable and there are sometimes periods of dead calm. Inevitably, therefore, complete absence of power at any particular site must be anticipated. Nor can absolute continuity of supply be expected from the interconnexion of wind-power plants located at widely separated sites; calm weather, with no wind speed of usable strength, may occasionally extend, for example, over the whole of the British Isles and perhaps over much greater areas. While interconnexion must increase the chances of some wind-generated power being available to the network, the feasibility of a constant power supply appears remote. But more conventional methods of power generation also have their uncertainties—as with hydro-power when the rainfall is unexpectedly low—and the premium to be paid for 100 per cent dependability may be very high; so high, that in some circumstances it may not be worth while paying. In an industrialised country it is essential that electricity should be continuously available and ready to serve its many purposes at the turn of a switch. The difficulty of providing such a service, except at a very high cost, in many parts of the world where the population is scattered, raises the question whether the inability of wind power, unaided, to do so should rule it out of court completely. During the last few years there has been a rapidly growing opinion that it should not be so ruled out, hence the widespread interest in the wind-power research and development which is now in progress in Great Britain, France, Denmark, Germany and several other countries.

WIND ENERGY AND POWER

Fortunately, the variability of the wind lies mainly in its strength at any particular time. Its total annual quantity at a given site is remarkably constant and records taken over periods up to forty years show a maximum variation from the average of less than 20%, with a variation in most years of under 10%; the constancy of wind is, in general, much better than that of rainfall. One can rely, therefore, with some confidence, upon an annual quantity of *energy* even though the availability of *power* at any given time is quite unpredictable; wind is a certain energy source but an uncertain power producer.

To clarify this question of uncertainty, and to regard it quantitatively, consider the typical 'velocity-duration' curve shown in Fig. 1. This is a curve in which the wind speeds through the year at a selected site—in this case a favourable one with an annual average wind speed of 25 m.p.h.—are classified according to their annual duration. Here the total period of dead calm is negligibly small. If a wind-driven machine to be used at this site were designed to start generating power at 13 m.p.h. giving full output for 25 m.p.h. and over, it would be in operation for some 7200 hours in the year (out of a total of 8760 hours) and would give full output for 4000 hours. The power curve—the power is proportional to the cube of the wind speed—is shown and the shaded area is proportional to the annual energy which would be extracted from the wind. (A reduction of the rated wind speed from 25 m.p.h. to 20 m.p.h. would lead to over 5000 hours of full output but the power capacity would be reduced in the ratio $\frac{20^3}{25^3}$ and the area swept by the windmill rotor would have to be correspondingly increased—at an enhanced constructional cost—to obtain the original capacity.)

It is convenient to express the windiness of the site in terms of the 'specific output' which would be extracted by a machine, with a given rated wind speed, located at the site. This specific output is measured in annual kilowatt-hours per kilowatt of capacity of the machine. Referring to Fig. 1, it is obtained by dividing the shaded area (to scale) by its own height. Thus, if the shaded area represents 400,000 kWh, and its height is 100 kW, the specific output is 4000 kWh per annum per kW. In spite of the units in which it is expressed, this figure is dependent only upon the wind régime at the site—which determines the shape of the power curve—and on the wind speed chosen to give full output; it is not influenced by either the size or type of the machine itself. The windier the site, the steeper the power-duration curve will be and the higher the specific output for a given rated wind speed.

THE SEARCH FOR GOOD SITES

An obvious first step in the investigation of wind-power possibilities is a search for especially windy sites and such a search was undertaken by the Electrical Research Association at the outset of its work on the subject (see DISCOVERY, March 1950). The wind survey now covers more than eighty sites in Great Britain and Ireland ranging from the Shetland Isles to Cornwall, the Channel Islands, and Bantry Bay in South-west Ireland. The sites chosen are all on well-shaped hills which vary in height from 150 to

FOUR GOOD SITES FOR WIND-POWER GENERATORS

1. SLIEVE GULLION.

2. BLOODY FORELAND.

3. BEN CHAIPAVAL, ISLE OF HARRIS.

4. GIVAT HAMOREH, PLAIN OF ESDRAELON, ISRAEL.

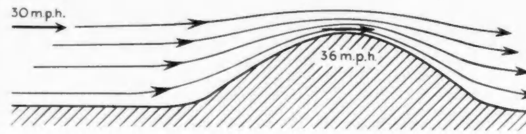


FIG. 5. Wind passing over a steep, smooth hill is speeded up. Thus a wind which reached the hill with a speed of 30 m.p.h. may be moving at 36 m.p.h. over the hill-top.

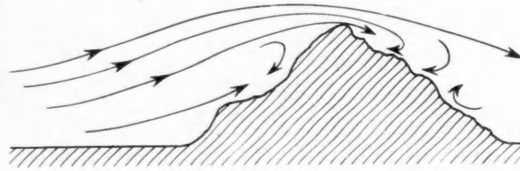


FIG. 6. This diagram shows the turbulent air flow that is associated with an irregularly shaped hill.

2800 ft.; the best have an annual average wind speed between 28 and 30 m.p.h. and the worst about 16 m.p.h. On first consideration, a survey of this kind might appear to be a rather difficult and costly job but, as the work has proceeded, with one or two new areas being tackled each year, the experience gained has shown the way to much simplification. Thus, for example, while at the start somewhat expensive recorders, mounted on 30-ft. masts and measuring hourly wind speeds, were thought to be essential, it proved possible later to replace many of them by simpler counter-type anemometers on 10-ft. poles. Not only are these instruments cheaper and much more easily installed, but their readings can be taken once a week by a person standing at the foot of the pole without any great effort or skill being required. This greatly eases the task of finding suitable local observers; changing recorder charts, and maintaining the recorders themselves, calls for some care and mechanical aptitude. In fact, the majority of the observers—without whose help the surveys would have been much more difficult to make—have been shepherds, crofters, farmers' sons, members of mountaineering clubs and other people who are in the habit of roaming the hills either for work or for pleasure. No more than ten minutes 'briefing' has been required to initiate them.

A counter anemometer measures simply the total run-of-wind, in miles, passing the instrument in a given period of time. To obtain the average wind speed one divides the miles of wind by the number of hours in this period. At one or two of the best sites in Great Britain, there have been over 250,000 miles of wind in the year (8760 hours) which gives an annual average wind speed exceeding 28 m.p.h.

One of the most important discoveries made in the course of this wind survey work has been that the specific output to be expected from a wind-driven generator, of given rated wind speed, can be estimated sufficiently accurately from a knowledge of the annual average wind speed at the site. This is because, over the operating range of wind speeds used for the machine, the shapes of the velocity-duration curves (see Fig. 1) are so similar for places with

the same average wind speed. As an example of the usefulness of this fact, if a machine is designed to give its full power output in a wind of 30 m.p.h. it can be estimated fairly accurately that its annual output per kilowatt of its capacity will be:

4400 kWh where the annual average speed is 25 m.p.h.
3150 kWh where the average is 20 m.p.h., and
1800 kWh for an average of 15 m.p.h.

If the design is such that full power is produced at 25 m.p.h. the output figures will be 5500, 4200 and 2700 kWh respectively, while a still lower rated wind speed of 20 m.p.h. will increase the outputs to 6200, 5350 and 3900 kWh.

Graphs can therefore be drawn to show the connexion between the estimated output (for a machine of given rated wind speed) and the average wind speed at the site, and it appears, from wind data which is being collected for sites in other parts of the world, that the same graphs may apply universally.

Probably there will be a little discrepancy if they are used for places where the wind régime is exceptional—where, for example, the wind speed is seldom much higher than the average and calm spells are infrequent—but, otherwise, the average wind speed may be used as a measure of output.

Some detailed records, giving hourly wind speeds, are, however, needed as a check on the wind régime and especially when there is in mind the possibility of using wind power, with only limited provision for energy storage, as the main source of power supply.

The importance of choosing good hill-top sites to obtain a high specific output is shown by the figures given in Table I, which summarises the survey results in Great Britain and Ireland. It compares the average wind speeds, and corresponding specific outputs, for groups of selected hills with those which apply generally to the districts in which the hills are situated.

A well-chosen site may thus give an output double or treble that which would be obtained at a less favourable spot on low ground in the same district. Long-term records from established meteorological stations are very helpful as an indication of the general order of wind speed applying to the district concerned, but the cube law to be used in power calculations makes the discovery of sites with wind speeds even two or three miles an hour greater than the normal of major importance to the economy of power generation.

TABLE I

Data for surrounding district		*Data for selected hill-top sites*	
Annual average wind speed	*Estimated* specific output*	*Annual average wind speed*	*Estimated* specific output*
(m.p.h.)	(Annual kWh/kW)	(m.p.h.)	(Annual kWh/kW)
17·5	2400	24 to 29	4100 to 5100
15	1750	19 to 25	2900 to 4300
12·5	1100	17 to 24	2400 to 4100

* For rated wind speed 30 m.p.h.

WIND-POWER PLANTS

Having found suitable sites the next question must be: "What kind of wind-power plant is to be installed?"

Extensive wind surveys of the sort already described are intended, of course, as a basis for the installation of large wind-driven electric generators, the output from which can be fed directly into main supply networks so saving coal—something between 1 and 1½ lb. for each unit of energy from the wind—if the principal generating stations are coal-fired. For good economy it is necessary that the networks shall be sufficiently widespread to permit connexion of the wind-driven plants without unduly long

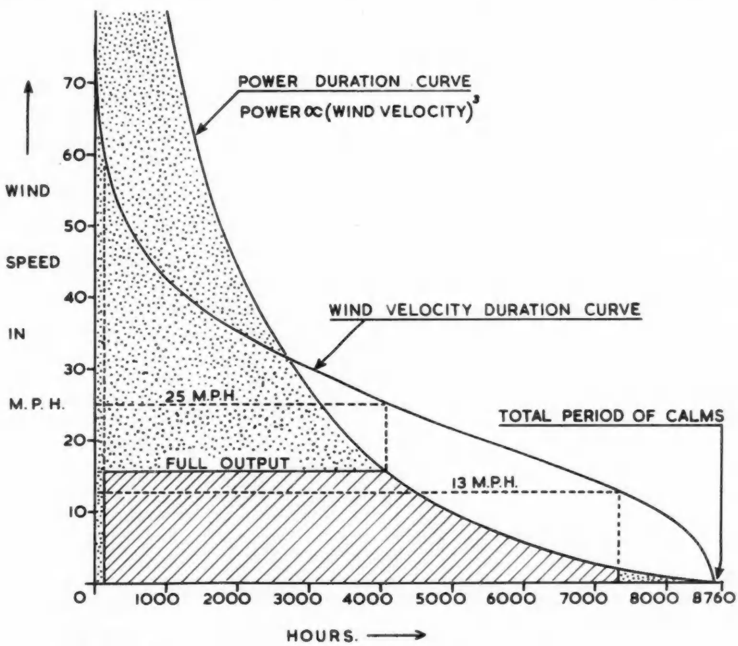


FIG. 7. The shaded area is proportional to the energy taken from the wind annually by a windmill designed to give full output at 25 m.p.h. and above. The dotted area is proportional to the annual energy wasted by controlling the output of the machine and by stopping it during very high wind speeds.

connecting lines, that the total power output from these plants can be accepted by the network whenever it happens to become available, and that the cost of the energy so generated shall be no more than that corresponding to the fuel component of generating cost at the thermal power station. The second of these requirements places some limitation on the total capacity of wind-power plant which could be used conveniently, but this is not a matter for concern at the present stage of development. The cost requirement is influenced by the specific output obtainable from a wind-driven generator designed to suit the wind régime and by the machine's capital cost to which the annual charges are proportional.

Design and costing studies in Britain and several other countries have indicated that machines of the propeller type, and of a size somewhere between 2000 and 4000 kW, are likely to be best and that it should be possible to build them at a low enough cost—around £50 per kilowatt—for wind power to be economic.

Smaller pilot plants, as a step towards the development of these large power units, are being built and tested in Britain (two 100-kW machines), Denmark (a 50-kW) and in France and Germany; there are projects also in Italy and other countries. Good progress is being made, but it is inevitable that such large machines—the propellers may eventually reach 200-ft. diameter—will take time to develop. They must be able to operate satisfactorily, with little maintenance, for long periods in continually varying winds, the speed of which rises at times to more than 100 m.p.h., and they must run at a constant rotational speed to match the fixed frequency of the alternating current network. Exposed for years to very rigorous climatic conditions, the materials of construction need careful choice. And, above all, the allowable constructional cost is fairly strictly limited.

To assist the designers by the provision of relevant data experimental studies of wind structure are being made. These include the measurement of the speed and duration of gusts, of vertical wind-speed gradients and of wind-speed distribution over a given area.

In addition to the large-scale machines which must be subject to step-by-step development, medium-sized wind-driven generators, of between 10- and 100-kW capacity, for which there is a widespread and insistent demand, are being built. Their construction presents less difficult problems and, when they are produced in quantity, their cost should lie within the economic range for the purpose for which they are intended. That purpose is to provide power for the very many communities, on islands and in remote places, which cannot easily be supplied from main power networks. These places have often sufficient wind for it to be used as an alternative to, or to supplement, other methods of power generation—usually by diesel engines. The capital cost of medium-sized wind-power machines may be between £100 and £150 per kilowatt, so that the cost of energy produced by them is likely to be two or three times as much as that from the largest wind-power plants even if they operate at a very windy site. But, counterbalancing this, generating costs for the diesel-driven generators with which they would be in competition are also much higher. The fuel component, alone, of generating cost at a diesel-engine power station having a capacity of a thousand or more kilowatts, located where transport charges for the fuel are not high, is of the order of 1*d.* per kilowatt-hour but this may rise to 3*d.* per kilowatt-hour or even more at stations in parts of the world where transport charges from the nearest port doubles or trebles the fuel cost. Under these circumstances medium-sized wind-power plants could generate energy at a competitive cost although the wind régime may not be very favourable. The wind 'transports itself' to the site so that it provides a potentially valuable source of locally available energy; the only real difficulty lies in the need to provide a power supply during calm spells and this calls for either some form of energy storage or a stand-by plant driven by some kind of fuel—in the absence of water power.

In reviewing wind-driven machines one must not overlook the small wind-driven electric generators, of capacity up to two or three kilowatts, which, with an accumulator battery to give energy storage, provide electric light and a little power for domestic purposes at isolated farms and country houses. There are also the water pumps driven by multi-bladed wind wheels through direct drive. Thousands of each of these kinds of plant are in use in many countries and do a most useful job.

And last but not least, because they were certainly the forerunners of all the modern wind-driven machines, there are the old-fashioned windmills, numbers of which are still in use in Holland, Denmark and other parts of northern Europe.

THE ECONOMIC APPLICATION OF WIND POWER

Considering the three scales of electricity generation by wind power—large, medium and small scale—with which modern developments are most concerned, we can dismiss the first and last briefly.

For large-scale generation, in Great Britain and in several other countries where main networks are fed from modern coal-fired generating stations, wind-produced energy would have to compete with a fuel component of generating cost which now stands at about 0·4*d.* per kWh. There is a prospect of its being able to do so at sites with annual average wind speeds of 20 m.p.h. or above.

Electrical energy from the small wind-driven generators may cost 6*d.* per kWh or more. But this figure depends upon the success achieved in making use of all the energy available and upon the attention given to maintaining the storage battery as well as upon the wind régime at the site. It is difficult to express a firm opinion about the economy of such small-scale generation of electricity without full knowledge of the possible alternatives at the site concerned, but it is easy to understand that electricity has a high amenity value at an isolated place and the cost mentioned may not be regarded as excessive.

Medium-scale generation presents interesting possibilities. A wind-driven machine generating (say) 50 kW could be used to supply a community of perhaps fifty to a hundred people whose precise demands for, and methods of utilising, energy would depend upon their location and their way of life. They may, for example, live on an island in a temperate zone and be occupied with fishing or

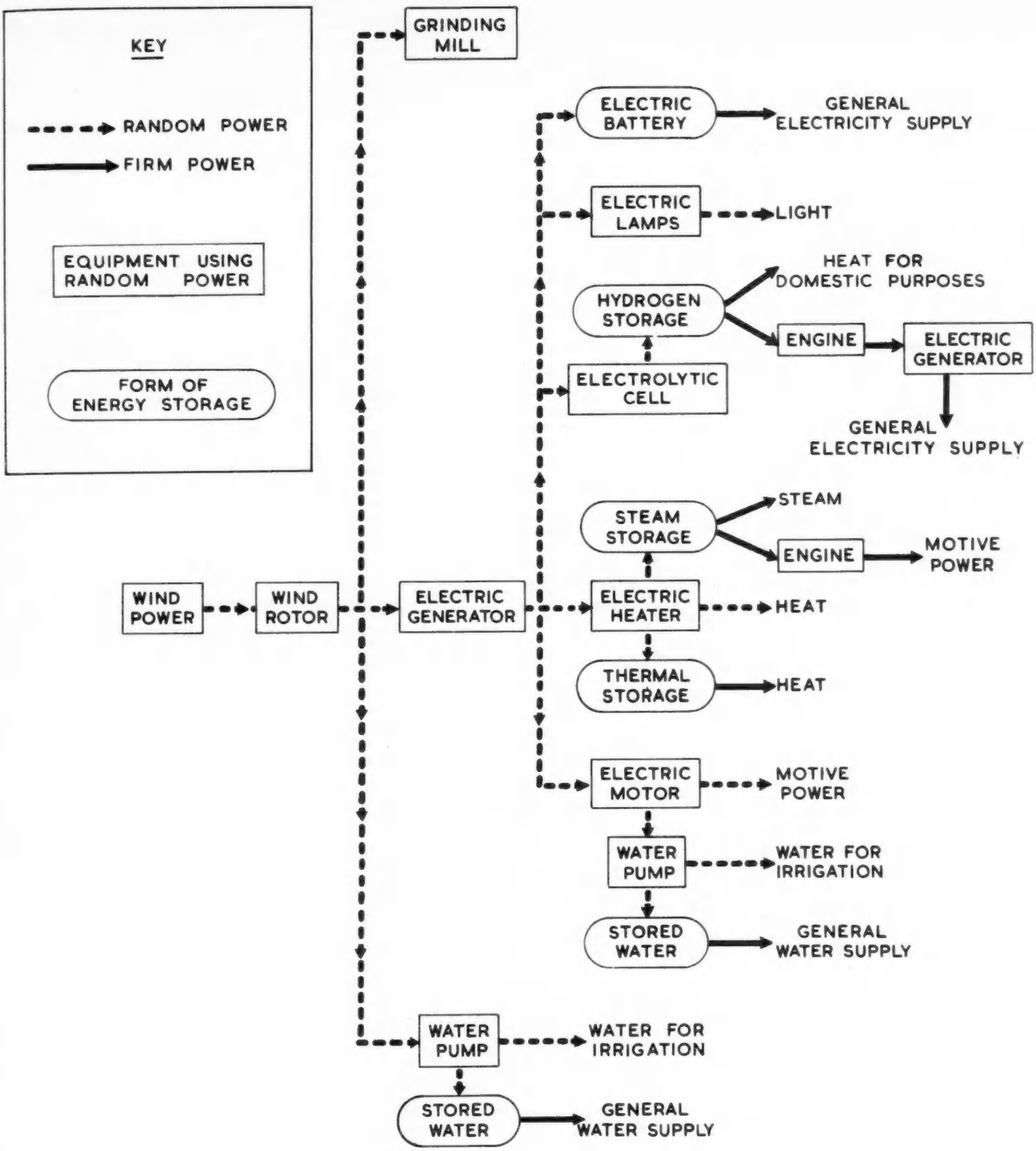


FIG. 8. The diagram shows the possible methods of using wind-generated energy with and without storage.

crofting agriculture or, on the other hand, they may be a newly established community in one of the semi-arid areas which are being developed. To cater for calm spells, when no wind power is produced, there are two alternatives. The first of these is a stand-by plant, such as a diesel-driven generator, and the second is the storage of energy.

If wind power is used in conjunction with a diesel plant the wind-generated energy saves diesel fuel and, in addition, reduces the lubrication and maintenance charges which are related to the number of hours for which the engine is used. For conservative estimation, only the fuel component of generating cost may be considered; this will vary, according to the location, from 0·9*d.* per kilowatt-hour

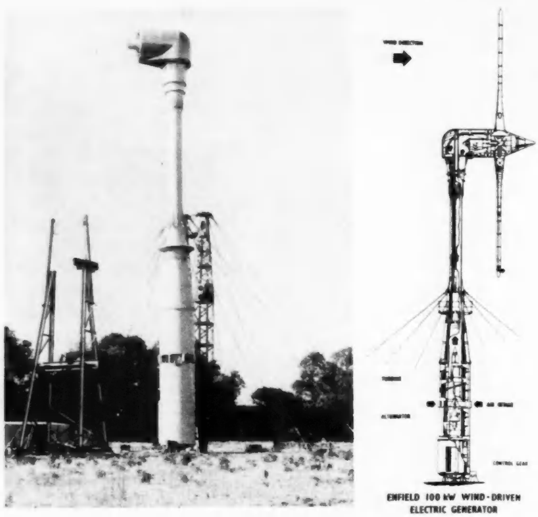


FIG. 9. The 100-kW wind-power generator erected by Enfield Cables Ltd., near St. Albans.

to about 3·7*d.* per kilowatt-hour. Table II shows what average annual wind speeds are needed for medium-sized wind-driven generators to be able to compete with the fuel component over this range.

TABLE II

Fuel component of generating cost with diesel generation	*Annual average wind speed for competitive costs with wind-power generation*
(pence)	(m.p.h.)
3·5	Above 9
3·0	Above 10
2·5	Above 12
2·0	Above 13
1·5	Above 14
1·0	Above 17
0·9	Above 18

The figures in the table indicate that even when the annual average wind speed does not exceed 10 m.p.h. wind power may be economic at places where diesel fuel is costly, but this speed must rise to 18 m.p.h. for economy where the fuel is cheapest.

If there is to be no stand-by plant and the wind-driven machine is to provide all the electric energy needed, the most economical arrangement may be as follows:

(i) Use the wind power to charge an electric battery of just sufficient capacity to store, in electrical form, the energy requirements for lighting during calm periods. (Both the capital cost and the depreciation charges for a battery are high, hence the limitation on its capacity.)

(ii) When there is sufficient wind, supply the loads which have no inherent storage as, for example, those involving electric motor drives.

(iii) Feed any surplus wind power into loads which have inherent storage. Examples of these are water pumping (which can be done at any time and which provides storage in the form of pumped water) and thermal storage heating for water, soil, or room space.

Suggestions have been made for methods of energy storage which are alternatives to the use of an electric battery. Thus, steam could be raised, by electric heating, and stored for later use in a steam engine or, again, hydrogen could be produced electrolytically, from water, and stored for use as a fuel either for heating or, in a specially adapted engine, for power production. The economy of such alternatives is, however, somewhat uncertain at the present stage of development.

Much depends upon the form in which energy is required by the consumer. Conversion from one form of energy to another involves both capital cost for the converting plant and power losses, so that the fewer the conversions the better.

In the diagram (Fig. 2), an attempt is made to show the various ways in which the energy from a wind-driven generator of medium size might be used without any form of stand-by plant. This diagram distinguishes between power which is produced, and used, at random times when the wind blows, and utilisation involving some form of energy storage. Also shown are the conversion processes in which the energy is not being effectively used but is being passed, through intermediate stages, from the form in which it is stored to that in which it is required. In reading the diagram, the general principle to be borne in mind is that the uses become less economical as one moves from the left, where the energy is in its original form, to the right where it has been passed through several stages of conversion.

CONCLUSION

In this brief review the aim has been to indicate some of the lines of investigation which are being followed to ascertain what may be the possibilities for wind power utilisation under different climatic and social conditions. Satisfactory progress has been made in experimental work and design studies needed as a basis for further development. Some of the results obtained show good promise for the future, but, if the final outcome is to be the really effective use of this source of energy by economic methods, the development must be done carefully and thoughtfully in all its steps. Unfortunately, from the point of view of the many potential users of wind power, this inevitably takes time to accomplish.

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UNICELLULAR ALGAE AS A SOURCE OF FOOD

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The world's population is increasing at a faster rate than output from agriculture, and a time may come when some of our food may have to be produced by unconventional methods. One suggestion is to culture unicellular algae.

This idea arose from researches into plant physiology in which certain algae have long been used as experimental subjects. Having noticed their remarkably rapid growth rate and the extent to which their biochemical composition could be varied, some American workers started, about six years ago, to consider the possibility of culturing these organisms on a large scale as a source of food. While the idea of mass culture of algae is new, their utilisation as a source of food is old. Our forefathers fed marine algae to their livestock, and the Japanese are renowned for the delicacies which they have made, for centuries, from seaweeds. The possibilities of the mass culture of unicellular algae have been studied in many countries, notably the U.S.A., Japan, Germany, Holland and England.

Like other green plants, algae obtain energy from sunlight, carbon from carbon dioxide and nitrogen from inorganic nitrogen compounds, but the amount of food they produce per acre can be very much higher than that from agricultural crops. This does not mean that the 'tools' they use for trapping the sun's energy and building up organic compounds are intrinsically more efficient than those used by higher plants. Photosynthesis can only work at optimum efficiency when the other requirements for growth are fully satisfied, and here it is easier to pamper algae than higher plants. Algae growing in culture solutions in enclosed containers can be easily supplied with all the nutrients they require and in the correct proportions. They can be fed the optimum amount of carbon dioxide and maintained at the most suitable temperature for growth. In the case of agricultural crops, which are at the mercy of the weather, it is usually impossible to satisfy exactly all their requirements. In addition the whole of these unicellular plants can be harvested and utilised, while only a part of the crops that the farmer grows is usually reaped, and in most cases a still smaller fraction of the actual material which is harvested is eventually used as food.

Another advantage with algae is that it may be possible by suitable agitation of cultures to expose the algal cells to intermittent light, which is used more efficiently than continuous light.* Moreover, an algal suspension of sufficient thickness can utilise more of the solar energy that falls on it than do ordinary plants occupying the same area. Most higher plants cannot be crowded so closely together and, especially when a crop is in the seedling stage, a large amount of the sun's energy falls on bare ground. Wastage of sunlight occurs, too, when long periods elapse between harvesting one crop and sowing the next. Thus it is easy to see why only a tiny fraction of the energy available to our planet is utilised, and so we can begin to speculate about our prosperity if we could find ways of using sunlight more efficiently than is possible by present methods of agriculture.

ALGAL SPECIES

It appears that very many species of algae could be cultured on a large scale as a source of food, but so far no systematic search has been made to find the most suitable species. *Chlorella pyrenoidosa* has been tried in America and Germany, *Chlorella ellipsoidea* in Japan and *Chlorella vulgaris* var. *viridis* at Jealott's Hill, but these are not necessarily the best, and attempts are being made to find more promising algae.

Chlorella vulgaris is a unicellular plant whose cells are spherical. The diameters of the cells of the strain used in our experiments at Jealott's Hill range from 3 to 10 microns. (A *micron* is a thousandth of a millimetre.) There are four distinct stages in its growth cycle. First, there is a lag phase, when cell division is very slow; secondly, an exponential phase which is characterised by rapid cell division, decline in average cell size and a decrease in the dry weight per cell; thirdly, a period when the rate of growth is more or less linear and not so great as in the exponential phase; fourthly, a period when increase in cell number is replaced by cell *expansion*. In the exponential phase, the number of fully-grown cells is doubled *every 9 hours*.

Chlorella reproduces by division of the cell contents into daughter cells; 2, 4, 8 or 16 of these are formed within each cell and are later liberated. In rapidly growing cultures only four daughter cells are usually produced per cell.

In *Chlorella* cultures a marked increase in cell number may occur without corresponding increase in dry matter—due presumably to cell division—and conversely a marked increase in dry matter may occur without an attendant increase in cell number, due presumably to cell expansion.

When ideal conditions are provided, growth occurs at a certain maximum rate. The limiting factor is not the rate of photosynthesis nor the rate of nitrogen assimilation but some other process, as yet unknown.

CULTURE TECHNIQUE

The growth and biochemical composition of *Chlorella* species are influenced by many factors, some or all of which are inter-related—a fact which accounts for the somewhat arbitrary approach that has been adopted up till now.

* The photosynthetic process can be divided into two main parts and *only the first step*, namely the conversion of light energy to chemical energy, *is photochemical*. A plant exposed to a flash of light, even of extremely short duration, fixes energy and the remainder of its anabolic processes, and this includes even the reduction of carbon dioxide, takes place in the dark. When a cell is supplied with sufficient light the rate of photosynthesis is dependent on the rate of the so-called 'dark reactions' and not on the photochemical process itself.

Culture vessel. The choice of the right container is highly important. In the laboratory many different types, varying from test-tubes to large Perspex tanks (Fig. 1), have been used. Polythene tubes somewhat similar to those used in pilot-plant studies in the U.S.A. are perhaps the most feasible for large-scale production. Tubes up to about 1000 ft. in length and 4 ft. wide could be arranged in parallel, and the depth of culture solution in these tubes would be about 4 in. This type of plant is said to be much cheaper than metal, concrete or wooden troughs. Open ponds probably require the least capital expenditure, but it would be difficult to keep them clean, obtain high utilisation of carbon dioxide and provide adequate stirring.

Culture medium. Chlorella thrives on a strictly inorganic diet. Nitrogen, phosphorus, potassium, magnesium, sulphur and iron are the major requirements; ammoniacal nitrogen is preferred to nitrate nitrogen. *Chlorella* is unique amongst plants in that it does not appear to require calcium. All the minor elements known to affect plant growth are usually added to the culture media, and some of these, especially iron, are kept in an available form by adding chelating agents;* ethylene diamine tetra-acetic acid, being biologically inert, is particularly suitable for this purpose.

Chlorella has been cultured or experimented with at hydrogen-ion concentrations ranging from about *p*H 5 up to about *p*H 9. Nobody has yet studied the effect of hydrogen-ion concentrations on the growth and composition of *Chlorella* in nutrient solutions maintained at constant composition throughout the growing period. In many experiments the *p*H has been allowed to drift, following the uptake of nutrients, from about *p*H 5 up to *p*H 8. Now the tendency is to maintain the *p*H at about 6.

The optimum temperature for *Chlorella vulgaris* and *Chlorella pyrenoidosa* is about 25°C. At 20°C and at 30°C, growth of *Chlorella vulgaris* is very poor, and cultures must be heated or cooled as the air temperature varies. The cost of heating and cooling may be reduced by culturing the algae in a region with a mild climate and by selecting species or strains which will grow well at reasonably high temperatures (e.g. 30–35°C). Recently, a strain of *Chlorella* was isolated and adapted to exponential growth at 39°C, and this organism, as well as possessing this desirable characteristic has a remarkably high growth rate. Other results have shown that some species of *Chlorella* can tolerate higher temperatures if they are kept cool at night; *Chlorella pyrenoidosa*, for example, gave the highest yield of dry matter when cultured in sunlight at 30°C and kept at 20°C during the night.

Supply of carbon dioxide. Chlorella absorbs carbon dioxide principally in the undissociated form (i.e. CO_2 or H_2CO_3) and little if any as the ions HCO_3 or CO_3. The amount of carbon dioxide in the atmosphere is insufficient for maximum growth of *Chlorella* species. Some experiments on the effect of carbon dioxide concentrations on photosynthesis show that carbon dioxide saturation is reached when the carbon dioxide content of the gas phase in equilibrium with the culture solution is 0·1% and that concentrations above about 5% are toxic. However, once the consumption of carbon dioxide in a culture is known, it should be possible to feed gas mixtures containing high concentrations and still maintain within the desirable limits the CO_2 content of the gas above the culture. This may be the cheapest method in large-scale production. It is perhaps worth noting that at Jealott's Hill we have successfully used gas mixtures containing 20% CO_2, the organism being cultured in open vessels. We were also able to show that the efficiency of utilisation of carbon dioxide by *Chlorella vulgaris* var. *viridis* is very high—approximately 85%. There is some evidence that, although *Chlorella* is unable to utilise bicarbonate, other algae (e.g. *Scenedesmus*) can do so rapidly.

Light. In most laboratory experiments with unicellular algae, artificial light is used. However, any large-scale process would, for economic reasons, have to depend on daylight. Only light of wavelengths shorter than about 7000 Å is active in photosynthesis and thus only about half of the solar energy falling on the earth's surface is capable of being utilised by plants or algae. There is some evidence that intense light bleaches thin suspensions of *Chlorella* cells, but no difficulties have been encountered in reasonably thick agitated cultures.

Cells grown in weak light are usually smaller than those grown in strong light. On this account cells are usually small when the population density of a culture is high.

At Jealott's Hill we have compared the growth of *Chlorella vulgaris* in continuous light with that when the cultures were illuminated for different periods every day, and we have found that keeping the cultures in darkness had a beneficial effect on growth in the subsequent light period—the yield per litre per unit of light was increased. Unfortunately chloroplasts use light most efficiently when the intensity of illumination is low. It has been shown that maximum efficiency is achieved by *Chlorella* at 100 foot

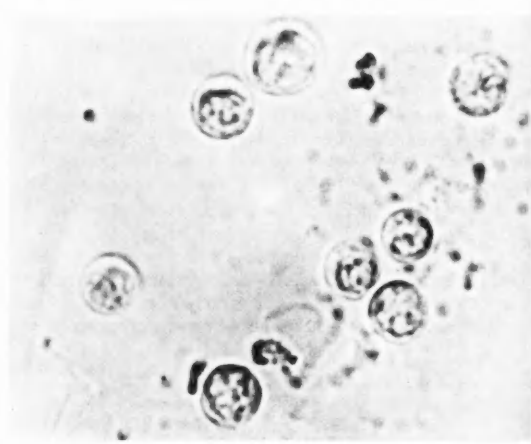

FIG. 1. Photomicrograph of *Chorella* cells. Magnification, about 1800 times. (*Courtesy of R. Brinsden, A.R.P.S.*)

* *A chelating agent*, is an organic compound capable of reacting with metallic ions to form a cyclic complex in which the metal atom forms part of a ring and is held claw-like between two groups of the molecule. In the presence of a chelating agent large amounts of a metal can be held in solution, in non-ionic form, in equilibrium with a small amount of the ion. As the ion is used up, dissociation of the complex releases a further supply.

candles. This phenomenon of light saturation imposes a serious limitation on the efficiency with which solar energy can be utilised by algae. It has been calculated that only 20% of the energy in the visible spectrum of sunlight having an intensity of 8000 foot-candles is used photosynthetically, the remainder being wasted as heat, and that a twentyfold increase in the incident energy results in only a fourfold increase in the amount utilised by the algae. There are two possible ways of solving this problem, firstly, by isolation or adaptation of algal strains to use bright sunlight efficiently, and secondly, by illuminating algal cells intermittently.

At the University of Texas, a strain of *Chlorella* is being studied which has a much higher saturation intensity, somewhere near 1000 foot-candles at 30°C. This might give about twice as great a yield per unit area of culture as the strains now used.

Many years ago, it was observed that the rate of photosynthesis in algal cells is much higher in flashing light than in continuous light. This suggested that yields from mass cultures might be considerably increased if intermittent illumination could be obtained by suitable adjustment of culture depth, agitation and population density. Conditions should be such that every cell is moved to the surface of the culture, exposed there to light for a given length of time and then returned to the interior of the culture where it remains in total darkness for a definite period of time. It has been calculated that in full sunlight the yield might be increased *sevenfold* by this treatment. (On cloudy days the effect would be less.)

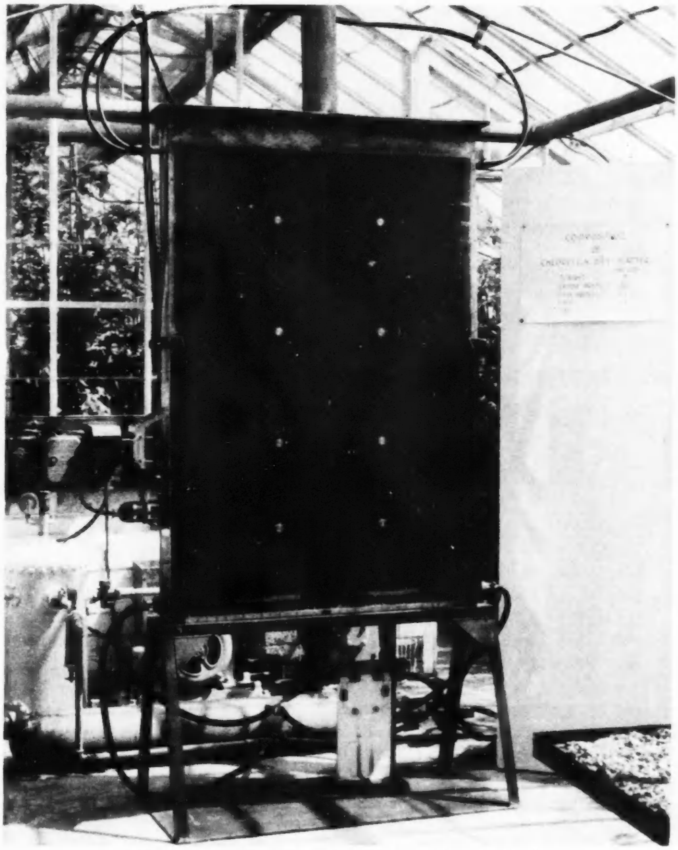

FIG. 2. Experimental culture tank used at Jealott's Hill for growing *Chlorella* on a fairly large scale. The sides of the tanks are of polythene.

In flashing light, the rate of photosynthesis depends on the ratio of light to dark periods, and the length of these periods, as well as on the total amount of light received by the alga. One result indicates that the flash time must not be longer than a few milliseconds and that the dark time must be at least ten times as long as the flash time for fully efficient utilisation of the incident light in photosynthesis. Another suggests that the benefits of intermittent illumination can be obtained with flash times as long as 30 seconds.

As yet there is very little evidence that the correct pattern of intermittence in illumination can be obtained in large-scale cultures. In one investigation, high turbulence considerably increased (by 70%) the yield of dry matter from a dense culture of *Chlorella pyrenoidosa* grown in a special ring-shaped chamber ($\frac{1}{4}$ in. wide) and illuminated with high-intensity artificial light. Much more information is required before the value of intermittent illumination can be judged, and it is felt that the economical provision of turbulent flow that will submit individual cells to favourable flash patterns, rather than to a random distribution of intensity variations, is probably a major engineering problem.

Depth of culture. Optimum depth of culture will vary with light intensity and with the way the light is used (whether intermittently or continuously). Laboratory tests have shown that yield of dry matter per litre is inversely proportional to depth of solution exposed to continuous illumination; therefore the yield per unit area is not affected by the depth of the solution.

A serious difficulty associated with large-scale production of *Chlorella* is that cells are non-motile and the cultures have to be stirred to obtain maximum utilisation of light, nutrients, etc. This agitation may prove to be one of the major operating costs associated with mass culture of algae.

CONTAMINATION

When culturing algae on a large scale it is impracticable to maintain sterile conditions and it may even be difficult to grow a pure culture of a single algal strain. Conditions which are suitable for, say, *Chlorella* are also more or less suitable for other algae, e.g. *Scenedesmus*; but this type of contamination should not seriously alter the value of the product. On the other hand it is difficult for bacteria, fungi

or actinomycetes, most of which obtain energy by oxidation of organic compounds, to live in *Chlorella* cultures. The media used for growing *Chlorella* are entirely inorganic and only a very small fraction of the carbon fixed by these organisms is excreted into the medium.

Organisms which can engulf *Chlorella* cells are potential contaminants. At Jealott's Hill we have frequently noticed certain protozoa, such as ciliates, in our cultures, but although they engulfed a number of cells they did not appear to reduce the yield. Serious infestations of rotifers occurred in the American pilot plant. Centrifuging at high flow rates selectively removed them and they were killed when the culture was heated to 45°C., but the effect of this temperature on the subsequent growth of *Chlorella* was not fully established.

HARVESTING

Centrifuging the culture solutions is the only satisfactory method of harvesting *Chlorella* cells. This is a costly process, and on a large scale it involves considerable capital investment. Costs might be reduced if cultures could be allowed to settle before treatment.

The paste obtained after centrifuging contains about 30% solids, and it decomposes in a short time if stored at room temperature. When dried it keeps for long periods and retains its dark green colour if stored in the dark.

Spray-drying appears to be the most satisfactory method for large-scale drying of *Chlorella* cells. The VioBin Process,* for simultaneous defatting and dehydration, could also be used for drying *Chlorella*. This separation might be very useful if the constituents of *Chlorella* cells were to be used separately.

YIELD OF DRY MATTER

The many factors that influence the growth of *Chlorella* and the variety of culture techniques used by different investigators are responsible for the wide variation in the yields obtained. In experiments, daily yields of about 40 grams per square metre of irradiated surface have been obtained, which is much less than the theoretical maximum of 110 grams per square metre (assuming complete utilisation of the visible spectrum of sunlight). On some occasions, under less favourable conditions, yields of 11 grams were obtained in the American pilot plant. Extrapolation of pilot-plant results suggest that an annual yield of 17½ tons per acre is not unreasonable to expect with the present technical knowledge. The wide gap between the yields obtained and the theoretically possible yield indicate the scope for improvement in culture techniques, etc.

COMPOSITION OF DRY MATTER

The composition of *Chlorella* cells is markedly influenced by the environment in which the organism is cultured. Thus the 'crude' protein content may be varied from about 7% to 88%, lipoids ('fats') from about 5% to 85% and carbohydrates from about 6% to 38% (on a dry matter basis).

* The VioBin Process consists essentially of heating vegetable or animal material with a suitable organic solvent. Fats dissolve in the solvent while water is removed by distillation with the solvent vapour.

Protein. So far, most workers have aimed at providing conditions for maximum growth and this results in a product with about 50% 'crude' protein and 47·5% 'true' protein. It has been shown that *Chlorella* protein contains the 'essential' amino acids.

Fat. Products with high lipoid contents can be obtained by keeping *Chlorella* cells, for long periods, in a medium containing little or no nitrogen. Under these conditions the daily yield of dry matter per litre is very low and although the percentage of lipoids in the cells is high the yield of lipoidal material is no greater than that from rapidly growing cultures.

The percentages of fatty acids, unsaponifiable matter and water-soluble saponification products in the lipoid fraction of a sample of *Chlorella* cells (which contained 23% lipoids) were found to be about 28, 12 and 60 respectively. The percentage of true fat in the total lipoid fraction can be varied from about 30 to about 90.

The fat from *Chlorella* resembles that from other vegetable materials, but is slightly less saturated. It contains triply unsaturated fatty acids, which are rarely found in vegetable fats. Palmitic acid is the predominant saturated fatty acid; only small amounts of stearic acid are present.

Carbohydrates. Very little is known concerning the composition of the carbohydrate fraction of *Chlorella* cells, or about the extent to which the composition of the fraction varies when the carbohydrate content of the cell is altered. Starch and sucrose have been isolated.

Ash. The total ash content of unwashed cells examined at Jealott's Hill was about 75%, but since the centrifuged product contains about 30% dry matter, and since about 2% of this consists of salts from the medium, the true ash content was about 5·5%.

Chlorella cells contain more phosphorus, sulphur and magnesium, and less potassium, than grassland herbage. The iron content is about the same in the two materials. Examination of products obtained by a semi-continuous process, where the nutrient status of the medium was kept constant, and of products from a batch process, showed that the percentages of inorganic constituents (notably phosphorus and potassium) in *Chlorella* cells were influenced by the composition of the nutrient solution.

Vitamins. Apparently the vitamin content of algal cells is markedly influenced by the age of the culture and conditions under which the organisms are grown. So far, the vitamin content of *Chlorella* cells has not been thoroughly investigated. Carotene, thiamin, riboflavin, niacin, pyridoxine, pantothenic acid, choline, biotin, vitamin B_{12} and lipoic acids have been found in products produced in the American pilot plant. The β-carotene content* of freeze-dried *Chlorella* cells is very high, being at least three times higher than that of good quality dried grass. From these results, it has been concluded that dried *Chlorella* could be an important source of vitamins, and that approximately a quarter of a pound of dried *Chlorella* would provide more than the minimum requirement of all except vitamin C. There is as much vitamin C in fresh *Chlorella* cells as in lemon juice, one of the best sources

* This carotene is the precursor of vitamin A.

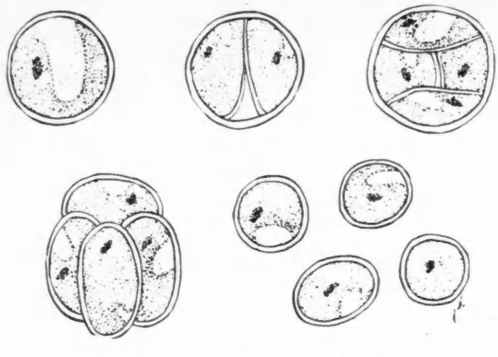

FIG. 3. Cells of *Chlorella pyrenoidosa* in a rapidly growing liquid culture. Magnification, about 2000 times. (*After "Algal Culture", Carnegie Institution of Washington Publication, No. 600.*)

of this vitamin, but unfortunately most of it is lost when the cells are dried.

Besides carotene, *Chlorella* cells contain chlorophyll a, chlorophyll b and xanthophylls. The chlorophyll content is influenced by light intensity and other factors affecting growth.

Other cellular constituents. Bacteria, fungi and actinomycetes are all able to synthesise valuable chemicals (e.g. alcohols, antibiotics, vitamins) and there is the possibility that some of the known 17,000 algal species may be capable of producing substances at least as valuable as those produced by other micro-organisms, a point which is particularly important when the economics of large-scale culture of algae is considered. This aspect is now receiving attention at the University of Maryland, where algae are being screened to find species which produce substances valuable to the pharmaceutical industry.

FEEDING VALUE

Much more investigation is necessary before the food value of *Chlorella* is fully known. Feeding tests carried out at the National Institute for Research in Dairying have shown that *Chlorella* protein is significantly better for young rats than yeast or groundnut protein but is inferior to milk protein. The diet fed contained 17% *Chlorella*, which at this level had no ill effects on the animals.

In 1951, experiments were carried out at Maryland University to assess the value of *Chlorella* as a source of nutrients for chicks. The inclusion of 10% *Chlorella* in place of an equal weight of soya bean meal in a diet deficient in riboflavin, vitamin B_{12} and vitamin A resulted in a very marked increase in growth and improvement in feed efficiency of young chicks. (The chicks were 16 days old when the experiment started and 4 weeks at the end.)

The improvement was attributed primarily to the high riboflavin and carotene content of the *Chlorella*, although, possibly, important quantities of several other B-vitamins may also be supplied by this amount of *Chlorella*. The addition of 0·1% *dl*-methionine to the *Chlorella* diet resulted in some improvement. In some experiments poor results were obtained which were believed to be due to the hygroscopic nature of dried *Chlorella* cells. Chicks fed with 2½%, 5% and 10% *Chlorella* developed impacted beaks, and those receiving 20% *Chlorella* developed impacted beaks and beak deformities, so that their food consumption and growth rate were lowered. Suitable processing could perhaps overcome this difficulty.

In 1952, a second chick-feeding experiment was carried out by the Ralston Purina Co., U.S.A. This time, chicks received a ration containing 2·5% of *Chlorella*. The growth of those chicks fed with *Chlorella* was very slightly depressed and apparently they did not eat as much food as the control group. Beak impaction was not a problem in this experiment.

In Venezuela, algal 'soups' have been fed to leprous patients. The soups were prepared by harvesting mixed cultures of phyto- and zoo-plankton species and boiling the product with salt. Patients of all ages drank these soups and liked them. Adults usually got 600 millilitres and children 400 millilitres per day. The length of treatment varied from one to three years. In the majority of cases there was a marked improvement in the general health of the patients which could be attributed to better nutrition or to the presence of some therapeutic substance in the microbial cells.

CONCLUSION

Unicellular algae can be cultivated on a large scale, and yields many times higher than those from agricultural crops can be obtained. The product has a very attractive composition and probably is a useful foodstuff, but so far nobody has estimated the cost of production. This aspect of the problem should be investigated immediately because it now appears that the success or failure of the mass culture of algae is a question of economics.

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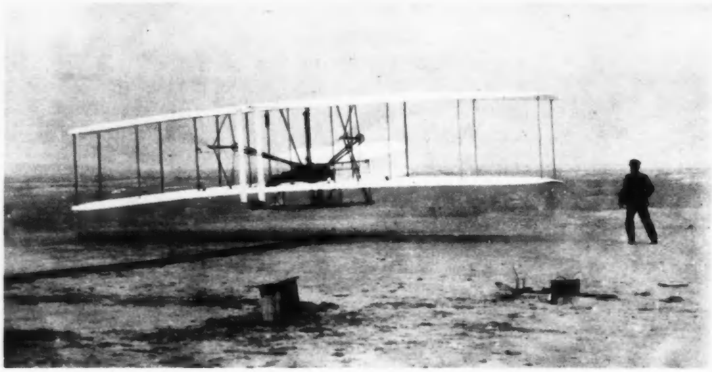

The photograph on left, taken on December 17, 1903, shows the first flight ever made in a powered aeroplane. Orville Wright is piloting it, his brother Wilbur is seen alongside the plane. The Kitty Hawk was wrecked after its fourth flight, when it flew 852 ft. in 59 seconds against a strong wind, and it was not rebuilt until 1928. (*Right*). Orville Wright, who died on January 31, 1948, at the age of 76.

FIFTY YEARS OF POWERED FLIGHT

SIR BEN LOCKSPEISER

K.C.B., F.R.S.

To fly like the birds was for centuries man's dream and desire. The Wright brothers succeeded where so many others had failed because of the relentless scientific attack they made on the problem of flight. "The world is not fully aware of all the tedious, gruelling, scientific laboratory work they had to do before flight was possible." They invented the wind tunnel to study and measure air forces, invented their own system of control and overcame difficulties of stability. They designed and built their own engine of some 20 horse-power, weighing not more than 240 lb.—itself a triumph of engineering at the time—and in the end designed and made a machine that would lift itself. Exactly fifty years ago this month, they flew this machine at Kitty Hawk in the United States and fulfilled the dream that man had cherished throughout the ages. It was a great achievement based on a rare combination of science, invention and engineering, and was one of the epoch-making events in history.

It is doubtful whether this machine ever climbed more than 10 ft. above the ground, for it had too much drag, too much weight and too little power to leave much margin for climb. But it was enough. A revolution in transport had been started. The main principles having been established and successfully demonstrated, progress was rapid. Six years after the flight of the Wright brothers, Blériot crossed the English Channel in forty minutes, and within sixteen years Alcock and Brown flew the Atlantic, for the first time, in less than seventeen hours. These three machines have changed the course of history.

SIGNIFICANCE OF STREAMLINED DESIGN

Low drag involves something more than absence of unnecessary parts projecting in the air stream. It implies certain standards of excellence in shape and lines; streamlined, in fact, and the lines we speak of are lines of air flow which, could they be made visible, as they can be experimentally by means of smoke, would be seen, in a perfect shape, to bend smoothly and flow snugly around curved surfaces of the structure, leaving no turbulent wake. Any departure from the ideal aerodynamic shape promotes the breakaway of the air flow from the surface and the formation of large-scale eddies or turbulence. This churning up of the air is sheer waste, and the power to produce it makes an unnecessary call on the engine. A very large effort has been spent in learning how to avoid this and to design and produce low-drag wings. By careful design and construction and smoothness of surface we can achieve laminar flow over more than half the depth of the wing (or chord as it is called), when a transition occurs from the laminar to a turbulent type of flow which gives rise to an increase of drag. The best aircraft flying today carry wings capable of producing this type of flow, and we may be able, in the future, by the use of slots in the wing or porous wing surfaces, to control the air flow by suction and push the transition point farther back to produce a near approximation to laminar flow.

For bodies moving in air at speeds below and not comparable to the speed of sound, the air behaves for all practical purposes as though it were incompressible, that is, its compressibility can be ignored. This does not hold as the speed of sound is approached. The velocity of sound in air at sea-level is about 760 m.p.h. and the effect of the compressibility begins to make itself sensibly felt above about 500 m.p.h. The effect of compressibility is to produce an increased drag rapidly growing with rising speed, and reaching at the speed of sound a value many times greater than would be encountered if the air remained sensibly incompressible.

It is not immediately obvious why the speed of sound should play such a dominating and decisive part, and

perhaps a few words from a purely physical aspect will not be out of place. At a speed well below the speed of sound or, as it is called, a low subsonic speed, the air conforms to a smooth flow pattern which extends forward of an aerofoil. The air ahead of the aerofoil is prepared in advance for its arrival, part being accelerated to flow over the upper surface and part over the lower surface. Clearly, the moving aerofoil possesses, as it were, a signalling system to warn the air ahead of its approach and allow it to take full advantage of its shape to slip through. What I have called the signalling system is based on changes of air pressure. The flow pattern is also a pressure pattern, for wherever the flow lines are curved a change of pressure occurs, giving rise to the lift and drag of the aerofoil. It is clear from the flow pattern that there is a pressure change ahead of the aerofoil, and this is the physical basis of the signal. Pressure changes in any medium are, however, not transmitted instantaneously, but with a particular velocity, dependent on the medium, and this velocity for pressure changes of the order of magnitude under consideration is the speed of sound in air. It follows, therefore, that if the aerofoil is travelling at or above the speed of sound (that is, at sonic or supersonic velocity) it is robbed of any means of signalling ahead. The air can no longer be prepared for its arrival. The aerofoil can no longer slip smoothly through the air: it now meets it, inevitably, head on, producing a shock wave which is the source of the largely increased drag.

This is fundamental, for it is impossible to avoid the formation of shock waves whenever the velocity of the air relative to the surface exceeds the local speed of sound. This is bound to happen at a forward speed appreciably below the speed of sound in the atmosphere, because the air is accelerated in its flow over a curved body such as a wing. The shock wave occurs at the downstream end of the local region of supersonic flow, and behind it the speed is subsonic. The position of the shock wave depends on the shape of the wing section and its incidence, as well as on the forward speed. (A film, taken in a wind tunnel at the National Physical Laboratory, illustrated the formation of shock waves on a conventional symmetrical aerofoil as the speed increased from subsonic to supersonic, and showed the movement of the first shock wave back towards the trailing edge as the speed increases at constant incidence.) When the shock wave moves back, the low pressure in the region of supersonic flow ahead of it extends over a larger fraction of the aerofoil surface, and there is therefore a movement of the centre of pressure with speed and incidence. This causes a considerable change in the stability of the aircraft. The occurrence of shock waves may also cause conventional control surfaces to become relatively ineffective, and this has led to the adoption of all-moving tail planes as in the North American "Sabre". At supersonic forward speeds a bow wave is formed, and the flow again becomes stable with no serious changes in the position of the centre of pressure as the speed or incidence is varied.

Matters are complicated by the fact that the speed of sound does not remain constant, but, because of the fall in temperature, decreases with altitude. It falls continuously from 760 m.p.h. at sea-level until the stratosphere is

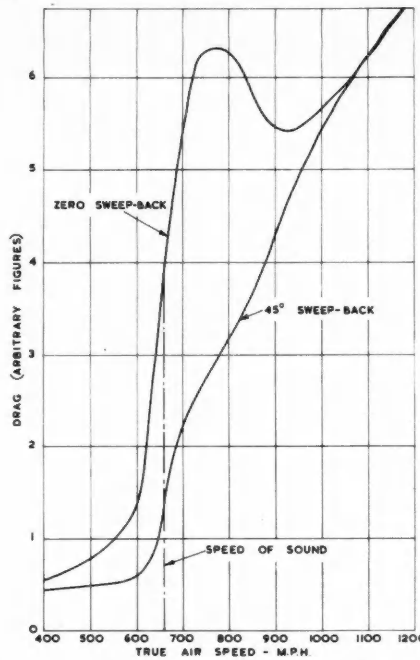

FIG. 1. The effect of sweep-back on drag at 40,000 ft. (equal wing areas).

reached, where the speed is 660 m.p.h. An aircraft flying at, say, 600 m.p.h. in the stratosphere is much closer to the speed of sound than when flying at this speed at sea-level. The significant and determining factor in compressibility phenomena is thus not the actual speed of the aircraft itself but the ratio of its speed to the velocity of sound at the altitude at which the aircraft is flying. It is usual, therefore, in dealing with the performance of high-speed aircraft to speak of the Mach number, that is, the ratio of the forward velocity to the local velocity of sound.

It is clear that the onset of shock wave conditions at high subsonic speeds can be delayed by reducing the acceleration produced by curvature, and high-speed flight therefore calls for slim wings, nacelles and bodies. These increase the speed at which shock waves first appear, called the critical speed, which can be raised still further by the use of swept-back wings, the effect of which is to reduce the effective thickness-to-chord ratio of the wing in the direction of flight, and hence to reduce the curvature of the wing surface. The effect of sweep-back in delaying the rise of drag is illustrated in Fig. 1, which compares the drag curves of two hypothetical modern aeroplanes of equal wing-areas—one square-winged and the other swept back 45 degrees. The diagram illustrates also that the advantage of sweep-back disappears at high Mach numbers. A typical modern fighter having swept-back wing and tail surfaces is the Hawker "Hunter".

High sweep-back, however, creates difficulties of its own. The twisting of the wing under load causes loss of lift at the wing-tips, which in the swept-back wing are well behind

the centre of gravity of the aircraft, giving rise to problems in pitch control. The degree of sweep-back required is related to the curvature of the wing surface which, diminishing progressively from the wing root to the tip, leads ideally to a crescent shape for a swept-back wing, thereby easing the control problem. This principle is embodied in the Handley Page "Victor" jet bomber.

The swept-back wing has been taken a step further in the so-called "Delta" wing aircraft, which embodies a swept-back leading edge and an unswept trailing edge, with the chord falling uniformly until it is zero at the tips. The main advantages of the "Delta" wing are its increased stiffness and stowage capacity: the former diminishes the wing-tip problem already referred to and helps to avoid flutter. The large centre-section thickness which becomes possible with a long centre-section chord enables jet engines to be completely buried in the wing, and space is also available for more fuel and payload. The latest "Delta" wing aircraft flying is the Avro "Vulcan" jet bomber.

PROPELLER VERSUS JET FOR MOTIVE POWER

We have, therefore, means at our disposal for reducing the drag of aircraft both up to and well beyond the speed of sound; but the drag at these high speeds is, however, formidable enough, and the thrust to overcome it has only become possible by the introduction of the gas turbine and propulsion by reaction from a very high-speed jet of gas. Propellers, like aircraft wings, are subject to compressibility drag effects, and the combination of forward and rotational velocities introduces increasing drag conditions over a considerable portion of the blade area after about 400 m.p.h. Up to this point, from comparatively low speeds, the propeller is a very efficient means of propulsion, efficiencies of about 85% being not uncommon; but at higher speeds compressibility drag becomes of increasing significance and the efficiency drops sharply. This is shown in Fig. 2, which contrasts this behaviour with the rise of efficiency of the jet as a means of propulsion, and explains why the use of a jet is so necessary for high-speed propulsion.

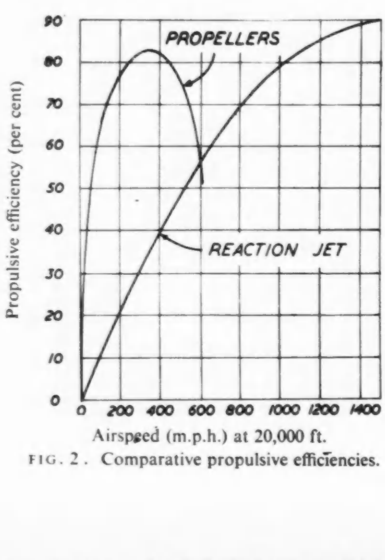

FIG. 2. Comparative propulsive efficiencies.

On this showing, the propeller ought to hold its own with the jet up to speeds of at least 500 m.p.h. and, theoretically, even beyond this figure, by the application to propellers of the principles of wing design for reducing compressibility effects already referred to. But, in practice, propulsion by jet is ahead of the propeller at lower speeds than this, because of other considerations. The elimination of the propeller eliminates also the disturbance of the air flow over the wing besides saving the weight and drag of the propeller. The turbo-jet engine is much lighter and occupies less space than a corresponding piston engine, offset though this is by the jet engine's higher fuel consumption. Range, of course, plays a determining part in the balance of these factors, but it is not the only one. The turbo-jet, particularly with axial flow compressor, can be built with a much smaller frontal area per unit of thrust than any other type of air-consuming engine, and it can be made to develop thrusts far in excess of anything hitherto obtainable. The superior efficiency of the jet over the propeller as a means of propulsion at high speeds, the absence of any propeller slipstream to increase drag, the comparatively small engine frontal area and the very high thrusts obtainable from these jets are the main reasons why the turbo-jet has swept the field in the high-speed range. Nor should we overlook the fact that the gas turbine is not fussy about the nature of its fuel. Aero piston engines demand expensively manufactured fuels of high octane number, whereas the aero gas turbine will burn either cheap motor spirit or paraffin. Paraffin is preferred because it gives less trouble with vapour-locking at altitude, and because its calorific value per unit volume is slightly higher.

Before the introduction of the gas turbine, the piston engine had already been developed to a high degree of excellence both in performance and reliability. Concurrently, its weight per horse-power had been reduced from the Wright brothers' 12 lb. per b.h.p. to just over 1 lb. per b.h.p. today; and in co-operation with the fuel technologists its specific fuel consumption (that is, the fuel consumed per b.h.p. hour) has been brought down from about 0·6 to 0·42 lb./b.h.p./hour. The aircraft diesel engine was not put into production in Britain, but in Germany the ingenious Junkers Jumo 205 opposed-piston two-stroke diesel engine had given consumption figures as low as 0·36 lb./b.h.p./hour in service. Unfortunately, it was very heavy for its power, weighing 1·8 lb. per b.h.p.

As I have already indicated, the gas turbine introduced by Whittle has revolutionised aircraft propulsion by making possible speeds which would be unattainable with a piston engine and propeller. The gas turbine can be used in two ways. First, all the power developed by the turbine is used to drive the compressor, and the exhaust is discharged as a high-speed, high-temperature jet of gas; this is the turbo-jet, of which the Rolls-Royce "Avon" is a typical example. Alternatively, part of the power developed by a more powerful turbine—commonly about one-third—can be used to drive a propeller; this is the turbo-propeller engine. Each type of engine has its place in the field of aircraft propulsion.

The propeller turbine, intermediate between the straight jet and the piston engine and propeller, is heavier than the straight jet, but makes much more economical use of the

same kind of cheap fuel. It can be quieter than any other kind of aircraft engine yet produced, and it is almost vibrationless. The Armstrong Siddeley "Mamba" is an example of this type of engine.

FUEL CONSUMPTION

Although we hear much about supersonic flight, which, of course, has been achieved, it is being more and more realised, if only because of the very high fuel consumption demanded by such high speeds, that it will be a very big step from our present subsonic civil airliners to the supersonic versions. When operating at extreme range, the "Comet I" takes off with 22 tons of fuel for 21 tons of aeroplane and 4 tons of crew and payload. Increasing attention is therefore being paid to the problem of greatly improving overall propulsive efficiency at high subsonic speeds. This can be done by the ducted fan or by-pass engine, which increases the mass flow of air through the engine and reduces the mean jet velocity. Such engines will probably reduce the fuel consumption by 25% as compared with a straight jet. The Rolls-Royce "Conway" is an engine of this type. It is a likely power plant for the De Havilland "Comet's" successor.

The present emphasis on jets does not mean that the piston engine can be entirely forgotten. In small sizes, the gas turbine cannot compete with it in first cost or economy of operation. In large sizes, provided one does not want to fly much faster than 300 m.p.h., the compound engine (part piston, part turbine) can beat all the others for very long-range operation. In the United States, compound engines have been produced by addition of multiple-exhaust turbines geared to the engine crankshaft. The Wright "Turbo-Cyclone" is an example of this: it has a cruising specific fuel consumption of 0·39 lb./hr./b.h.p. and has been chosen to power the latest American long-range civil aircraft, such as the "Super-Constellation". In Great Britain the compound engine has, in my opinion, been tackled more fundamentally, and we now have the Napier "Nomad", which uses a two-stroke diesel engine with a high-pressure exhaust turbine. This engine has achieved the lowest specific fuel consumption ever recorded for an aircraft engine (0·33 lb./hr./b.h.p.) and weighs only 1·2 lb. per b.h.p.

MODERN ALLOYS IN AIRCRAFT DESIGN

The metallurgist has played a leading part in the great advances made in both aircraft and engines. When the Wright brothers flew, aluminium was little more than a scientific curiosity, a low-density weak metal of about 5 tons per sq. in. tensile strength. Modern aircraft aluminium alloys have a tensile strength as high as 40 tons per sq. in. with a density one-third that of steel, and the proof stresses of aluminium alloys have been almost doubled since the time of the First World War—an outstanding achievement providing a striking example of progress made under the spur of necessity.

The development of light alloys which could be rolled into sheet of high strength coincided with important advances in structural science and led to the introduction of the cantilever monoplane, which created a major revolution in aircraft engineering. The main structural change was the introduction of stressed skin or monocoque construction. This innovation killed two birds with one stone. It replaced fabric with a more robust material, more capable of resisting deformation and change of aerodynamic shape, and it enabled the surface covering to contribute very substantially to the strength of the structure as a whole. It made the most efficient use of material by placing it as near as possible to the outside surface. The skin now provides nearly all the torsional stiffness, and it also contributes to the bending strength of the wing, thus enabling a reduction in the weight of the main spars to be made. The tail surfaces have developed on similar lines, while the fuselage early lent itself to monocoque construction.

The recently developed magnesium alloys, especially those containing zinc and zirconium, have proved of great value in light-weight castings, such as those for the reduction gear casings of aircraft gas turbines, for they have a strength/weight ratio nearly 20% greater than that of the best aluminium alloys. Magnesium alloys are also becoming available as forgings, extrusions and rolled sheet with very promising engineering properties. High specific strength is not their only virtue: they can be machined faster and more easily than any other engineering material, and they have completely displaced aluminium alloys in aircraft wheels. Magnesium alloys now account for about one-third of all light-alloy castings supplied to the aircraft and engine industries, and the proportion is growing.

Light alloys based on aluminium and magnesium suffer, however, a rapid loss of strength with rise of temperature. This has for long been a serious drawback in piston engines, where the piston temperature has limited cylinder diameter and power output. In the gas turbine, compression raises the temperature of air leaving a compressor with a compression ratio of 6:1 to well over 200C°, and copper-bearing aluminium alloy blades are now giving way to those of titanium alloys containing chromium and iron, the strength characteristics of which with temperature, compared with those of aluminium alloys and sintered aluminium powder, are shown in Fig. 3. Titanium alloys which have so far been investigated are twice as strong as aluminium alloys for one and a half times the weight, and further improvements in strength/weight ratio may be achieved.

Alloys for aircraft, however, require to be not only strong for their weight but stiff also, and, in this respect, present-day titanium alloys are, on a comparative basis, inferior to both aluminium alloys and steel by about 10%. This matters a great deal; for the development of the modern aeroplane, particularly as regards speed, has introduced a new criterion in design, namely, structural stiffness, which is now a consideration comparable in importance with strength. A reasonable degree of stiffness is essential on practical engineering grounds, but the main concern is with flutter. This is a complicated aeroelastic phenomenon in which, at a particular speed, dependent on the characteristics of the structure, oscillations occur of progressively increasing amplitude, rapidly ending in structural disintegration. Flutter is the skeleton in the cupboard of all high-speed aircraft designers, for all structures are liable to flutter in a wind in certain circumstances, and the higher the speed the greater the risk. The best a designer can do is

to ensure, so far as he can, that the flutter speed is well above the highest practical flying speed. Various measures can be taken to this end, but high stiffness both in bending and twisting is the principal safeguard.

In addition to strength and stiffness at the minimum cost in weight, a third criterion—fatigue—has to be taken seriously into account by the designer in his choice of materials, and this is becoming more and more a matter for anxiety as new alloys of higher static tensile strength come into use. Aircraft have to be designed to deal with not only their normal static loadings but also additional repeated loadings, due mainly to gusts encountered in the atmosphere, which vary greatly according to time and intensity. In the structural laboratory, complete wings are subjected to fluctuating loads broadly representative of a flight in bumpy weather until failure occurs.

PROBLEMS OF TAKE-OFF AND LANDING

As a consequence of these advances in the several fields of science, technology and design, and with a recognition of the vital part played by the skill of pilots, aircraft speeds have increased steadily with the years, and at an increasing rate, from a maximum speed of 70 m.p.h. in 1910 to more than 700 m.p.h. in 1953. Fighter aircraft are, of course, built primarily for speed, but transport aircraft and civil airliners have to compromise on speed to fulfil the requirements of range and economy. Their maximum speed is therefore lower and their cruising speed, at which fuel is used more economically, lower still. Nevertheless, it is of interest to note that the cruising speed of jet civil aircraft is much closer to their maximum speed than is the case with propeller-driven aircraft.

High speed, however, carries certain consequences, among which is a high rate of fuel consumption which cuts into payload. We can get anywhere in the habitable world in hops of about 2000 miles or so, and, as we pay for speed by fuel consumption, a fast aircraft at the beginning of a 2000-mile flight is virtually a flying tanker. About half its all-up weight is accounted for by fuel. This is not the only price we pay for speed, for higher flying speeds have involved higher landing and take-off speeds, and fast long-range aircraft are not only inevitably heavy but also demand long and expensive runways. Aircraft *weight* determines the thickness of concrete for a given sub-grade, and take-off speed, for a given acceleration, the length of runway. At the London Airport the longest runway is rather less than two miles, and concrete a foot thick is used on a stable gravel base. The airport covers nearly 3000 acres and its estimated cost on completion is of the order of £21 million. If aircraft are to become larger and heavier, as is likely, the provision of concrete runways presents very serious economic problems.

The flying boat offers a possible means of escape. Until comparatively recently, the performance of the flying boat was inferior to that of the corresponding land plane, but several advances have now made it a serious competitor. The flying boat always had the advantage of being able to dispense with an undercarriage, which, in a modern large

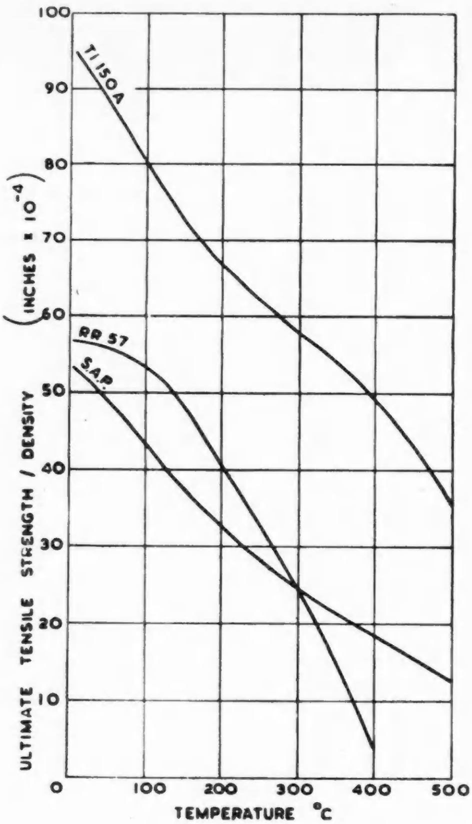

FIG. 3. Variation of ultimate tensile strength with temperature for famous materials for gas-turbine compressor blades.

aeroplane, may account for 6% of the total structure weight; but this was for a long time more than offset by the excessive size and weight of a hull which had to carry the propellers high above the water to keep them clear of the spray. Jet propulsion has changed all this, and a smaller hull, combined with improvements which can now be made in its aerodynamic design, may well tip the balance in favour of a flying boat for all-up weights of 50 tons and above.

Finally, we have in recent years come back to where Leonardo da Vinci began, and devoted serious attention to the rotary wing aircraft. It can never match the fixed-wing aeroplane for speed, but it can land on and take off from a small space, rise and descend vertically, and fly horizontally at a speed which gives it an advantage in door-to-door times for journeys of a few hundred miles.

(*This article is the substance of a lecture to the Liverpool British Association meeting, delivered on Sept. 4th.*)

Far and Near

Lord Cherwell retires from Government

Lord Cherwell, who has been Paymaster-General since 1951, announced his resignation from that appointment at the end of October. He has now returned to Oxford and taken up again his duties as Professor of Experimental Philosophy, after two years' leave of absence which is the maximum possible under the university statutes.

Two years ago Cherwell accepted the post of Paymaster-General and a seat in the Cabinet, which meant that he became in effect Sir Winston Churchill's personal scientific adviser. He was given the special responsibility of advising the Government on atomic energy questions. During his term of office the pace of atomic energy development in this country certainly seems to have quickened, and the stage has now been reached when, for example, it is possible to look forward to Britain's first atomic power station coming into operation within a relatively short time. Sir Christopher Hinton's statement to a New York conference about the atomic reactor which should be pumping electric power into the Grid in three or four years' time certainly conveyed the impression that the tempo of atomic energy development has been speeded up, and it is interesting to note that this very encouraging statement was made on the very same day that Cherwell's retirement from the Government was announced. This coincidence was a happy one in that it served to emphasise that considerable progress on the atomic energy front has been made during the two years Cherwell has held office.

Cherwell's last official mission was a visit to Washington where he discussed atomic matters with American experts.

One decision taken by the Government during Cherwell's term of office was the decision to switch the control of atomic energy development from the Ministry of Supply to a non-departmental agency. The details of the new organisation have been worked out by the Waverley Committee (comprising Lord Waverley, Sir Wallace Akers and Sir John Wood). This organisation is the "Atomic Energy Corporation" of the Government White Paper issued last month (Cmd. 8986, price 6d.)

Even his critics must admit that Cherwell has certainly left his mark on Government policy with regard to atomic energy. In his letter of resignation to the Prime Minister he expressed his readiness to place his services at the Government's disposal, and Churchill replied as follows: "It is a consolation that you are willing to continue giving me your advice from time to time on scientific questions. In particular, your close connexion for more than 10 years with the development of atomic energy invests you with an authority on that subject which will continue to be of outstanding value to Her Majesty's Government." It is worth recording that Churchill has relied on Lord Cherwell to a great extent for scientific advice during their association over the past twenty-five years. His great services to Britain have been recognised by the conferring of a Companion of Honour on Lord Cherwell.

Night Sky in December

The Moon.—New moon occurs on Dec. 6d 10h 48m, U.T., and full moon on Dec. 20d 11h 43m. The following conjunctions with the moon take place:

December

2d 04h	Mars in conjunction with the moon		Mars	7° N.
3d 12h	Saturn	,,	Saturn	8° N.
4d 21h	Mercury	,,	Mercury	7° N.
5d 10h	Venus	,,	Venus	5° N.
19d 23h	Jupiter	,,	Jupiter	3° S.
30d 23h	Mars	,,	Mars	7° N.
31d 02h	Saturn	,,	Saturn	8° N.

In addition to these conjunctions with the moon, the following conjunctions with bright stars occur:

December

7d 02h	Mars in conjunction with Spica	Mars 3·5 N.
12d 07h	Venus in conjunction with Antares	Venus 5·2 N.
16d 09h	Mercury in conjunction with Antares	Mercury 5·4 N.

The Planets.—Mercury is a morning star, rising at 5h 45m, 6h 40m and 7h 45m on Dec. 1, 15 and 31, respectively, but in the latter case the planet is too close to the sun to be seen. Venus is a morning star, its times of rising being 6h 25m, 7h 10m and 7h 45m, respectively—in the latter case only about 20 minutes before sunrise. Attention has already been drawn to the conjunction of Venus with Antares on the morning of Dec. 12. The stellar magnitude of Venus is −3·4 throughout the month and about the end of Dec. practically all the illuminated disk is visible, as might be expected from the fact that towards the end of January 1954 the planet is in superior conjunction, that is, the earth the sun and Venus are nearly in a line so that the full illuminated disk is turned towards us. Mars is a morning star, rising about 2h 55m throughout the month and is close to θ Virginis early in Dec., but about Dec. 27 it has moved close to κ Virginis. Attention has already been drawn to the conjunction of Mars with Spica on Dec. 7. Jupiter rises at 16h 45m, 15h 40m and 14h 30m on Dec. 1, 15 and 31, respectively, and is in opposition on Dec. 13, which implies that about that time the planet rises near the time of sunset and sets near the time of sunrise. During the month it is visible throughout the night, shining as a star of magnitude −2·3 and close to ζ Tauri about the beginning of the month. Saturn, a morning star, rises at 4h 30m, 3h 40m, and 2h 45m, on Dec. 1, 15 and 31, respectively; in the early portion of the month it lies a little S. of κ Virginis and its slow movement away from the star in an easterly direction can be noticed as the month progresses.

Myxomatosis

Myxomatosis has occurred among two rabbit communities in Kent and one in Sussex. This disease is caused by a virus that is spread by mosquitoes (*Aedes* and *Culex*), blackflies (*Simulium*) and at least one species of flea. As readers will recall the virus is being exploited in Australia as a weapon of biological control against the rabbit.

In Britain the myxomatosis outbreaks are regarded rather differently, and steps have been taken to stamp out the disease. There is a risk that it may spread and affect tame rabbits, and the Ministry of Agriculture is examining the possibility of inoculating domesticated rabbits to protect them. The Minister told the House of Commons (October 30) that a committee has been set up to advise on matters arising in connexion with myxomatosis in rabbits and the action that should be taken by the Government. The chairman of the committee is Lord Carrington.

In France myxomatosis has spread very rapidly through the wild rabbit population this year. The infected animals have been dying in large numbers, to the chagrin of all sportsmen who enjoy rabbit shooting. The French outbreaks are supposed to have resulted from the action of a doctor who followed up the Australian experiments and tried his hand at controlling French rabbits biologically. Unlike the Australian scientists who spread myxomatosis, and for so doing received the official blessing of the Government that employs them, this French doctor is most unpopular and at best is regarded as an inept meddler with nature, a Sorcerer's Apprentice whose virus had got out of control. The Pasteur Institute has produced a vaccine to protect unaffected rabbits.

Contrariwise, the correspondence in *The Times* about the recent outbreaks has sided with the myxomatosis virus, and accuses the Ministry of Agriculture of interfering with the spread of a useful disease!

Careers in Biology

A useful careers booklet of 32 pages, entitled *Biology as a Career*, has just been published by the Institution of Biology. This can be obtained direct from the institute's secretary, MR. D. J. B. COPP, Tavistock House South, Tavistock Square, London, W.C.1. The price is 2*s.* 6*d.* post paid.

D.S.I.R. Liaison Officer for Wales

The D.S.I.R. has appointed DR. R. O. JONES as its first resident Liaison Officer in Wales. His task will be to study the industrial position in Wales with a view to assisting in the identification of industrial

problems amenable to research and in the application of existing knowledge and research facilities to meet Welsh needs. It is hoped to provide a link between Welsh firms and the research laboratories of the D.S.I.R., the Research Associations and others, and to make more readily accessible in Wales the scientific information already available within the D.S.I.R. organisation.

A graduate of University College, Swansea, and of King's College, London, Dr. Jones has been a member of the headquarters staff of D.S.I.R. for several years. His office will be in the Welsh Board of Health Building at Cathays Park, Cardiff (telephone: Cardiff 5120).

Science Masters in Scotland: Investigating Committee Appointed

In our leader about the dearth of science masters we mentioned the committee headed by SIR EDWARD APPLETON which is "to consider and report on the causes and effects of the present and prospective shortages of teachers of mathematics and science in Scottish secondary schools, and to suggest remedies".

The other members of the committee have now been announced and their names are as follows:

PROFESSOR E. T. COPSON, Professor of Mathematics, St. Andrews University.

REV. PROFESSOR J. M. GRAHAM, Lord Provost of Aberdeen.

MR. R. L. GWILT, president of the Faculty of Actuaries in Scotland.

DR. W. J. JENKINS, chairman of the Nobel Division of Imperial Chemical Industries, Ardeer.

MR. A. G. MCKIMMIE, headmaster of Allan Glen's School, Glasgow.

MR. W. G. MARSKELL, superintendent of the Research Department of Babcock & Wilcox, Ltd., Renfrew.

DR. A. R. MURISON, rector of Marr College, Troon, ex-president of the Educational Institute of Scotland.

DR. H. B. NISBET, Principal of Heriot-Watt College, Edinburgh.

MR. J. N. TOOTHILL, general manager of Ferranti Ltd., Edinburgh.

MR. H. P. WOOD, Director of Studies, Jordanhill Training College, Glasgow.

MR. A. L. YOUNG, Director of Education, Aberdeenshire.

Communications in connexion with the committee should be addressed to the Secretary, Committee on the supply of Teachers of Mathematics and Science, St. Andrew's House, Edinburgh, 1.

Pears Cyclopaedia

The 62nd edition of Pears Cyclopaedia (1953–4), just published, is remarkably good value. It contains 992 pages and costs 12*s*. 6*d*. The "General Information" section contains many scientific entries, there is a medical dictionary plus a section on First Aid, Radio, Television and Radar are given a section of their own written by the B.B.C. engineer, T. W. Bennington, as is Photography. The volume contains the most conveniently accessible list of Nobel Prizewinners, which is complete up to 1952.

THE BOOKSHELF

The Hand Produced Book by David Diringer (*London, Hutchinson's Scientific and Technical Publications, 1953, 604 pp., 60s.*)

The present volume is the second of a trilogy tracing the history and evolution of the art of writing. The first volume, *The Alphabet* has already become a standard work of reference, and the third of the series, *Illumination and Binding of the Hand Produced Book* is now in preparation. In a detailed and scholarly account, the author summarises and interprets modern research on the early history of writing, and has produced a connected survey of the development of the book from Sumerian clay tablets of the second millennium B.C. to the medieval liturgical books of western Europe. The account is both thorough and detailed, but is perhaps more likely to be used as a work of reference than as a readable account 'for the cultured layman' for whom it was designed. The main theme of the book is a connected account of the development of west European books, but Dr. Diringer has also collected a vast amount of material on the development of writing in such diverse places as India, Japan and Central America. An interesting fact emerges from the book: the establishment in Korea in the 14th century of His Majesty's Stationery Office, and printing by movable copper types as early as 1403, half a century before this method was first known in Europe. R.A.W.

Impossible Adventure by Alain Gheerbrant; translated by Edward Fitzgerald (*London, Victor Gollancz, 1953, 390 pp., 16s.*)

This is an exciting story of exploration by a member of a small expedition that crossed from Colombia to Brazil in 1948-50. Its unique interest lies in the fact that these white men were the first ever to reach the Amazon across the Sierra Parima, which took them through unexplored territory occupied by primitive tribes with barbarously fascinating customs, as for instance the initiation ceremony of the Piaroas in which boys are put through the ordeal of being stung by giant ants.

Mushrooms and Toadstools by John Ramsbottom (*New Naturalist Series, Collins, London, 1953, 306 pp., 84 colour photographs, 58 black and white photographs, 30s.*)

Dr. Ramsbottom is to be congratulated on a very notable and welcome addition to the New Naturalist series of books. His long professional connexion with the Natural History Museum, his devoted services to the British Mycological Society, his unfailing kindness to beginners, and the time and energy he has expended in spreading a knowledge of the fungi in this and other countries, have grouped around him a host of friends; to that host this book will add many more. Were it not that the reference might well be misunderstood, I would like to call him, not the Robert Brown of the fungal world, as do the editors of the New Naturalist, but the Rabelais of the fungal world, for *Mushrooms and Toadstools* is full of the great qualities—breadth of vision, tolerance, dislike of pretence, and above all, healthy good sense—which are the great features of *Gargantua and Pantagruel*: it reminds me, too, of Burton though those who know little of the *Anatomy of Melancholy* could be misled by the linking of Ramsbottom with Burton—there is in fact nothing melancholy in *Mushrooms and Toadstools*.

Mushrooms and Toadstools is indeed a book. It is fragrant with the delightful odour of the wet mouldy earth after rain, the scent of autumn woodlands, and also with the quiet and yet stimulating smell of ancient books. It calls up delightful memories of the author, full of benign good-humour, displaying the treasures he has found in the field and in books. Many of these treasures are now placed before a wider public; many others have had to be put aside for want of room, but we are encouraged to hope that they may come to view in another place.

The output of the results of specialist investigation continues to increase at an alarming rate; science, we are told, has become a matter of knowing more and more about less and less. If, as it seems, that is true, there cannot but follow loss of breadth of vision, and maybe ultimate blindness. "If the blind lead the blind, both shall fall into the ditch." As things are going, the student who would obtain and retain some general view of his subject, may well feel that he is rather in the plight of the old-time criminal, who was lashed to a stake close to low-water mark and left to drown in the rising flood. An author who has the knowledge, the desire and the experience to write a comprehensive and understandable account of a wide field of knowledge is particularly welcome in these days. In *Mushrooms and Toadstools*, Dr. Ramsbottom has produced such an account in a style to command our gratitude and our admiration. Like Antaeus in the fable, he has renewed his strength by contact with the earth, and, unlike Antaeus, he has prevented the Hercules of academic mycology from lifting him off his feet and crushing him in the air; for he keeps ever before him the living active fungus. He does not disdain the speculative aspects of the subject. Following his matured opinions, he expounds some speculations fully and discusses them temperately, while he dismisses others with a pungent amusing quip.

In a book of less than 300 pages of text it is not possible to include all that is known

and all that has been guessed about the larger fungi. Yet there is no major branch of mycology—apart from plant pathology, which can hardly find a place here—which has been passed over. The careful reader will be left with a broad, clear impression of the larger fungi as they live, and with some knowledge of the smaller fungi. The broad impression will not be without ornament, for the 'curious knowledge' mentioned by the editors of the New Naturalist in their preface to the book, that curious knowledge which is above rubies, enlivens almost every page of the book, adding life and gaiety to what could so easily have been mere dry detail. These items of special knowledge are conspicuous in the historical parts of the text, but they abound throughout the book; many have never before appeared in print, at any rate in any readily accessible form.

Very hearty praise is due to the illustrations, both plain and coloured. The reproductions of the coloured photographs taken by Paul de Laszlo will certainly send other photographers out among the toadstools, and the black and white pictures are excellent. Though *Mushrooms and Toadstools* is not a handbook of systematic mycology, the pictures and the lists of fungi characteristic of a number of well-defined habitats will be of great service to field naturalists in checking the identifications they have made from the formal books on systematics. None of the pictures and nothing in the text will tempt the uninformed to eat toadstools which might do them harm.

Mushrooms and Toadstools must be in the hands of every naturalist. It will do much to forward the work of popularising a knowledge of the larger fungi, that work which has lain very close to the author's heart for so many years. It will provide beginners in academic botany with an admirable example of a scholarly approach to the study of the subject in general, and of the fungi in particular.

B. BARNES

Dry Rot and Other Timber Troubles by W. P. K. Findlay (*London, Hutchinson's Scientific and Technical Publications, 1953, 267 pp., 25s.*)

Dr. Findlay of the D.S.I.R. Forest Products Research Laboratory is a recognised authority on the pests which damage timber, and as a specialist on wood fungi was largely responsible for building up the Wood-Destroying Fungi Section in the British National Collection of Fungi. This work deals not only with the fungi which attack timber, but also those which cause disease in standing trees (e.g. *Armillaria mellea*, *Fomes*, *Polyporus*). There is one chapter on the destruction of wood by insects (mainly beetles, e.g. the death-watch, house longhorn, furniture and powder-post beetles), and this is designed to enable the reader to identify with reasonable accuracy the individual insect responsible for a particular example of damage, and to guide him to an appropriate method for treating the attack.

Prevention of attack by insect and fungus pests is every bit as important as the treatment of infested timber, and the author has an excellent chapter about wood preservatives, in which he deals systematically with all the different materials that are available and with the various ways in which these can be applied to the best effect. Whether your problem is to treat a few seed boxes or to protect a large batch of telephone poles, you will find the solution here. The care of timber after felling, which concerns forestry men and timber merchants, is the subject of another chapter.

The prevention and cure of dry rot and wet rot in buildings are more than adequately dealt with, and separate chapters give practical information about the protection of timber in farms and gardens; decay in ships and marine works; damage in vehicles, aircraft, industrial installations, such as cooling towers, and packing cases.

This monograph covers the ground very thoroughly, and is likely to become a standard work. It will be particularly useful to all who have to deal with practical timber problems.

Photography: Its Materials and Processes by C. B. Neblette (*London, Macmillan, 5th ed., 1952, 500 pp., 47s. 6d.*)

In recent years developments in photography have occurred in so many directions that encyclopaedic and up-to-date reference books become more necessary than ever. The new edition of Neblette goes a long way to satisfy this need. The work is a composite one, and as such there is naturally some unevenness and there are some omissions.

The book starts with a wide review of light sources including a comprehensive practical treatment of electronic flash. This is followed by full treatment of photographic optics, a rather sketchy chapter on filters and a very full one on photographic shutters.

It is difficult in such a book to know how much space should be given to the chemistry of photography. The theory and practice appear to be usefully covered. Diffusion transfer reversal processes are described in full detail.

The growing importance of studying the theoretical side of tone reproduction is recognised.

The various practical aspects of photographic methods are covered in some detail. Diazo processes are hardly given their importance. Xerography and other physical processes of obtaining a photographic image are not mentioned.

Possibly in view of rapid developments in colour photography the review of this subject is less complete than might have been expected. Colour correction and masking is given a good qualitative survey. While most other books on the subject tend to confuse by excessive mathematics this seems to err a little the other way.

In spite of minor omissions the book is to be recommended for the large amount of up-to-date information it contains.

A History of Flying by C. H. Gibbs-Smith (*London, Batsford, 1953, 304 pp., 21s.*)

This is a most entertaining book, and would make an excellent Christmas present. Its interest is historical and not technical, and it takes the story of flying right back beyond the Wright Brothers, Lilienthal, Henson and Stringfellow to Leonardo da Vinci and Roger Bacon, and even beyond that, to times where the facts get lost in the mist of myth and legend. A great deal of space is devoted to the early balloonists. There is perhaps rather too much about the failures of aviation, so the author has little enough room for the successes; over two-thirds of the space is devoted to the pre-Wright brothers phase.

Classified Advertisements

OFFICIAL APPOINTMENTS

ASSISTANT (SCIENTIFIC): The Civil Service Commissioners invite applications for pensionable posts. Applications will be accepted up to 31 December, 1953.

Age at least 17½ and under 26 years of age on 1 January, 1953, with extension for regular service in H.M. Forces, but candidates over 26 with specialised experience may be admitted.

Candidates must produce evidence of having reached a prescribed standard of education, particularly in a science subject and of thorough experience in the duties of the class gained by service in a Government Department or other civilian scientific establishment or in technical branches of the Forces, covering a minimum of two years in one of the following groups of scientific subjects:

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Further particulars and application forms from Civil Service Commission, Scientific Branch, Trinidad House, Old Burlington Street, London, W.1, quoting No. S.59/53. Application forms should be returned as soon as possible.

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APPLICATIONS are invited for the following vacancies.

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including overseas pay and temporary c.o.l.a. of approximately 15 per cent of basic salaries (£880–£1200, £540–£1000 and £540–£780 respectively). Temporary appointments would carry slightly higher salaries. Grading for lecturers and point of entry into scale according to qualifications and experience. Partly furnished houses provided, rent according to basic salary. Free first-class passages, once each way for each tour of service, for persons appointed, their wives and up to three children under 13. Income tax at Gold Coast rates. Generous home leave on full salary.

Write for further information to Secretary, Advisory Committee on Colonial Colleges, 1 Gordon Square, London, W.C.1. Closing date for applications (6 copies) 15th December, 1953.

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APPLICATIONS are invited for entry of boys in September, 1954, to WELBECK COLLEGE, Worksop, Notts. The object of the College is to prepare boys for entry to the Royal Military Academy, Sandhurst, with a view to their eventual commissioning as Regular Officers in the technical corps of the Army. The age of entry will be between 15¾ and 16¾ years of age (approximately). Tuition and Board will be free but the cost of other personal maintenance will be borne by parents according to their net incomes. Closing date for applications is 10th January, 1954. Prospectus and application forms can be obtained from the War Office (AG10/127) London, S.W.1.

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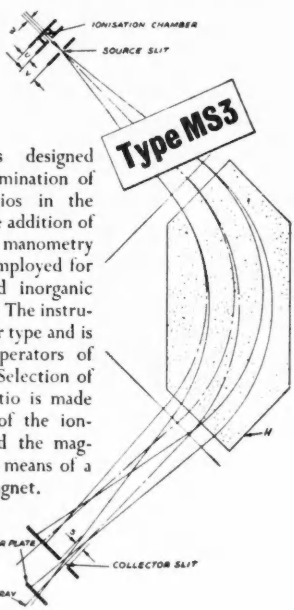

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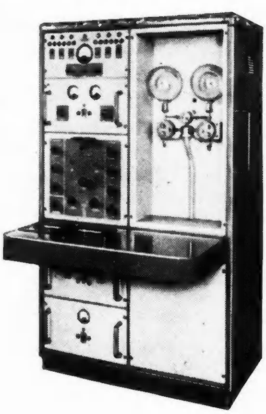

Details of the MS3 Mass Spectrometer are given in leaflet 905/12-1 which will be forwarded on request.

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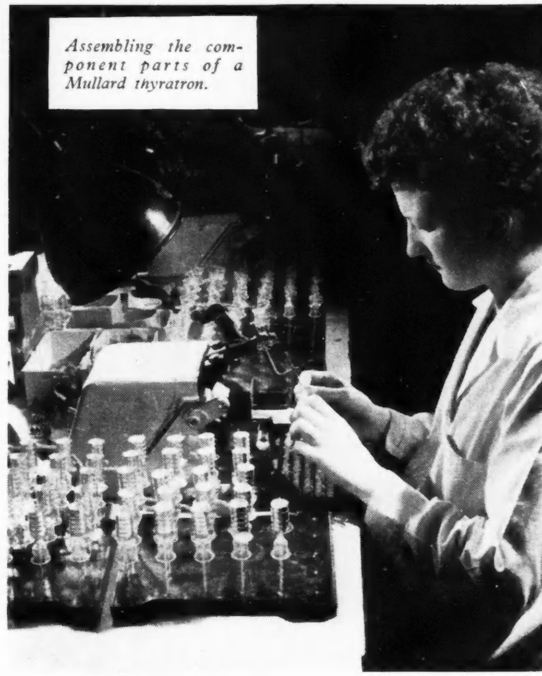

Assembling the component parts of a Mullard thyratron.

PROGRESS IN ELECTRONICS

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